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Stock structure, life history, fishery and abundance indices for spiny dogfish (*Squalus acanthias*) in Atlantic Canada

Structure du stock, cycle biologique, pêche et indices d'abondance de l'aiguillat commun (*Squalus acanthias*) dans l'Atlantique canadien

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Abstract

In 2003, an intensive 5-year research program on Canadian dogfish was initiated by the Department of Fisheries & Oceans (DFO), conducted in cooperation with the dogfish fishing industry through a Joint Project Agreement (JPA). This report is an overview of all new and published work done to date to better understand the stock structure, migration patterns, abundance trends and current state of the Canadian portion of the Atlantic spiny dogfish population. The information and advice provided is expected to be used in the management of the fishery and to guide future discussions with the U.S.

Spiny dogfish have many characteristics of a metapopulation, whereby some dogfish aggregations colonize or depart Canadian waters *en masse* at periodic multi-year intervals, and then remain resident in those waters for many years at a time. For the most part, dogfish tagged in Canadian waters have remained in Canadian waters, and those tagged in U.S. waters have remained in U.S. waters. However, there is some movement (10-20%) between Canadian and U.S. waters, with the Gulf of Maine region being the primary mixing ground. The existence of a metapopulation would imply that managing northwest Atlantic dogfish as a single, well-mixed stock would be inappropriate.

In the absence of a viable population model, it was not possible to estimate the exploitation rate for spiny dogfish in Atlantic Canada. However, biological studies indicate that the Atlantic population of spiny dogfish is more productive than is the northwest Pacific population. However, the long gestation period (~ 2 years), late age of sexual maturation and slow growth rate for spiny dogfish means that the species is relatively unproductive compared to other fish species.

Spring minimum trawlable biomass estimates for spiny dogfish in Canadian and U.S. waters show similar trends, increasing from the early 1980s to the early 1990s, then declining somewhat to the present. Mean values for both indices were around 500,000 mt in the early 1990s, declining to about 300,000 mt in 2007 for the Canadian index. The Canadian spring index is considered to be a better indicator of total adult biomass than is the summer index.

It is not currently possible to estimate trends in mature female biomass for spiny dogfish in Atlantic Canada. However, mature female biomass in the U.S. spring RV survey has declined to much lower values in recent years, albeit with an upturn in the last two years. Without knowing the extent that Canadian spawners contribute to the health of northwest Atlantic dogfish metapopulation, it may not be wise to increase the exploitation rate on mature females.

Résumé

En 2003, un programme quinquennal de recherches intensives sur l'aiguillat canadien a été entrepris par le ministère des Pêches et des Océans (MPO), en collaboration avec l'industrie de la pêche de l'aiguillat, dans le cadre d'une entente relative à un projet conjoint (EPC). Le présent rapport donne un aperçu de tous les travaux, nouveaux et publiés, à ce jour, permettant de mieux comprendre la structure du stock, les habitudes migratoires, les tendances de l'abondance et l'état actuel de la portion canadienne de la population d'aiguillat commun de l'Atlantique. L'information et les conseils fournis seront probablement utilisés pour la gestion de la pêche et pourraient guider les discussions futures avec les É.-U.

L'aiguillat commun affiche un bon nombre des caractéristiques d'une métapopulation en ce que certains groupes d'aiguillats colonisent ou quittent les eaux canadiennes en masse, à intervalles périodiques de plusieurs années, puis résident dans ces eaux pendant de nombreuses années. De façon générale, des aiguillats marqués dans les eaux canadiennes sont demeurés dans les eaux canadiennes et d'autres, marqués dans les eaux américaines, sont demeurés dans ces eaux. Toutefois, on constate certains déplacements (de 10 à 20 %) entre les eaux du Canada et des États-Unis, la région du golfe du Maine étant le principal lieu de mélange. L'existence d'une métapopulation porterait à croire que la gestion de l'aiguillat commun de l'Atlantique Nord-Ouest en tant que stock unique mixte est inappropriée.

En l'absence d'un modèle de population viable, il n'a pas été possible d'estimer le taux d'exploitation de l'aiguillat commun dans l'Atlantique canadien. Cependant, des études biologiques montrent que la population de l'Atlantique est beaucoup plus productive que celle du Pacifique Nord-Ouest, mais la longue période de gestation (~ 2 ans), la maturation sexuelle tardive et le lent taux de croissance de l'aiguillat commun font en sorte que l'espèce est relativement peu productive comparativement à d'autres espèces de poisson.

Les estimations de la biomasse minimale chalutable d'aiguillat commun au printemps dans les eaux canadiennes et américaines présentent des tendances similaires, augmentant à partir du début des années 1980 jusqu'au début des années 1990, pour diminuer quelque peu par la suite, jusqu'à aujourd'hui. Les valeurs moyennes des deux indices étaient d'environ 500 000 tm au début des années 1990, diminuant jusqu'à environ 300 000 tm en 2007 pour ce qui est de l'indice canadien. L'indice canadien printanier est considéré comme un meilleur indicateur de la biomasse adulte totale que l'indice d'été.

Il n'est pas possible actuellement d'estimer la tendance de la biomasse des aiguillats femelles matures dans l'Atlantique canadien. Toutefois, la biomasse de femelles matures, selon le relevé du printemps du navire de recherche aux É.-U., a diminué jusqu'à des valeurs beaucoup plus faibles, ces dernières années, quoiqu'on ait constaté une reprise ces deux dernières années. Sans connaître la mesure dans laquelle les géniteurs canadiens contribuent à la santé de la métapopulation d'aiguillats de l'Atlantique Nord-Ouest, il n'est peut-être pas avisé de hausser le taux d'exploitation des femelles matures.

Background

Most Atlantic Canadian landings of spiny dogfish are taken in directed handline, longline, and gillnet fisheries. Catches were unrestricted prior to 2002. Since 2002, precautionary directed catch quotas based on past catches have been in place for the Scotia-Fundy region. The quota since 2004 has been set at 2500 mt. Quotas to this point have not been based on scientific advice, and there are no restrictions on discarding and bycatch in other fisheries.

In recognition that spiny dogfish stock components are found on both sides of the Canada/U.S. border, an information exchange forum was held at the Bedford Institute of Oceanography in 2003 so that science, fisheries management and industry from both the U.S. and Canada could exchange information and views about spiny dogfish biology, management and fisheries. The meeting was recognized as the first step in a process to work towards more integrated management of spiny dogfish.

In 2003, an intensive 5-year research program on Canadian dogfish was initiated by the Department of Fisheries & Oceans (DFO), conducted in cooperation with the dogfish fishing industry through a Joint Project Agreement (JPA). The JPA provided for the collection of large numbers of at-sea and landed samples of dogfish catches that were used in analyses of commercial catches and dogfish biology.

This report is an overview of all work done to date to better understand the stock structure, migration patterns, abundance trends and current state of the Canadian portion of the Atlantic spiny dogfish population. The information and advice provided is expected to be used in the management of the fishery and to guide future discussions with the U.S.

Distribution and Habitat

Spiny dogfish (*Squalus acanthias*) are small squaloid sharks common both on the bottom and in the water column of coastal temperate oceans around the world. Dogfish populations are known to be present in the waters off of Europe, Argentina, New Zealand and Japan, as well as in the northeast Pacific and northwest Atlantic. In the northwest Atlantic, dogfish are common from North Carolina to southern Newfoundland, and can be found further to the south and north (Fig. 1).

Dogfish on the Scotian Shelf are usually associated with bottom water temperatures between 0 and 12 ^{0}C throughout the year, although 6-11 ^{0}C appear to be the preferred temperatures (Fig. 2). The species has been collected at depths from 0-350 m on the Scotian Shelf, although it is most commonly observed at depths of 50-200 m (Fig. 2). At the northern limit of their range, Kulka (2006) reported that dogfish in Newfoundland waters (NAFO 3LNOP) were most commonly associated with water temperatures of >5 ^{0}C and water depths of 100-250 m.

Reproduction

Spiny dogfish are ovoviviparous, with the young feeding and growing off a yolk sac in utero before being born alive (Jensen 1966; Ketchen 1975; Nammack et al. 1985; Hanchet 1988; Jones and Ugland 2001; Henderson et al. 2002). In maturing females, immature eggs turn yellow and grow to a diameter of 20-45 mm. The mature eggs pass through the shell gland, where they are fertilized and become enclosed in a protective capsule (candle) prior to passing through to the uterus. Candled embryos break free of the capsule after about a year, living as free embryos feeding off the yolk sac within the uterus for the remainder of the gestation period. The embryos

continue to grow as the yolk sac shrinks, but embryos that have completely resorbed the yolk sac may remain in the uterus for some time before being born. This reproductive cycle takes 22-24 months, making it one of the longest gestation periods known for any vertebrate.

As part of an intensive study of dogfish conducted in cooperation with the commercial dogfish fishery, we studied the sexual maturation and growth of dogfish collected on research surveys and as part of the commercial fishery (Campana et al. in press). Sexually mature and pregnant females were distributed throughout the waters of southwest Nova Scotia and the Bay of Fundy during the summer and fall, but moved offshore to deeper waters in the winter (Fig. 3). Females of mature size have also been observed in the southern Gulf of St Lawrence and off southern Newfoundland. The fork length at 50% maturity for males was 55.5 cm (= 63.6 cm total length (TL)) at age 10, while that for females was 72.5 cm (= 82 cm TL) at age 16 (Fig. 4). Free embryos were observed in 62% of all pregnant females (n=1491). The number of free embryos in any given female ranged between 1 and 14 with a mode of 5 (Fig. 5). Larger females tended to have significantly more free embryos, such that a 90-cm FL female had on average four times as many free embryos as a female 60 cm FL (Fig. 5). Free embryos first became apparent in June at a fork length of 16 cm, and would be expected to reach their birth size of 22-25 cm during the winter. Our results confirmed that the dogfish gestation is around 2 yr, thus making the species relatively unproductive.

Pupping grounds have not been observed in either Canadian or U.S. waters. However, large aggregations of mature females occur in deep warm waters off the edge of the continental shelf and in the deep basins of the central shelf throughout their range in the winter. Based on the presumed birth months in late winter, pupping occurs in these deep offshore areas. Small juveniles are seldom collected in either Canadian or U.S. research surveys, but those that are collected are found in the same areas as the mature females in winter. It appears likely that the small juveniles pursue a largely pelagic existence for the first few years of their lives before moving onto the continental shelf. Based on the presence of mature females and young juveniles in offshore waters each winter, pupping most probably occurs in both Canadian and U.S. waters.

Age and Growth

The accuracy of dogfish age interpretations using spine growth bands has been confirmed using bomb radiocarbon dating (Campana et al. 2006). To determine the age structure of Canadian Atlantic dogfish, a total of 525 spiny dogfish were aged with a mean precision (CV) of 12% and a longevity of 31 yr. Males and females grow at similar rates until the size and age of male maturity, after which male growth rate slows considerably (Fig. 6). Two-parameter von Bertalanffy growth equations using a fixed size at birth (=25 cm) gave $L_\infty = 78.0$ and $K = 0.099$ for the males, and $L_\infty = 119.5$ and $K = 0.042$ for the females. Northwest Atlantic dogfish appear to grow more quickly, mature at a younger age, and die at a younger age than do northeast Pacific dogfish. Thus the Atlantic population is more productive than is the northwest Pacific population.

The relationship between dogfish length and weight is shown in Fig. 7. Although fork length is a more accurate measure of length for dogfish (since it does not involve depressing the upper lobe of the tail), some authors have used total length in their reports. The inter-conversion equations are as follows:

Fork Length = -1.5 + 0.90 • TL
Total Length = 3.1 + 1.09 • FL

Stock Structure and Migration

Genetics

To test for evidence of population structuring in Canadian dogfish, tissue samples were analyzed for microsatellite DNA from dried muscle on dogfish spines (n=307) collected around Nova Scotia and Newfoundland (Fig. 8). Samples were collected from six locations in three different years, with the majority of the samples having been collected in 2006. Only the Upper Bay of Fundy (UBF) sample set included collections from multiple years (2005 and 2006). Additional samples were requested from U.S. waters, but these have not yet arrived. Seven microsatellite loci developed for dogfish (McCauley et al. 2004) were used for the microsatellite analysis. The analysis was conducted by the Aquatic Biotechnology Lab at the Bedford Institute of Oceanography by Lorraine Hamilton and Koren Spence.

The amplification success rate at each of the six loci varied between the sample collections. For the UBF samples the majority of the failures occurred in the 2005 UBF samples. That sample set had the highest number of failures (at least one failed amplification at 21 out of 23 samples) and, as that was the sample set of the lowest size, this resulted in a very high failure rate. The failure rate was not associated with the age of the samples as the Sambro samples were the oldest (2003 collection) and had the lowest failure rate. The 2005 UBF sample was dropped from further analysis due to the high sample failure rate combined with the low sample size.

Summary statistics for all loci at each sampling location indicate that deviations from Hardy-Weinberg expectations were significant for nine of the sample location and locus combinations (Table 1, HWE rows), and the overall probability of the combined sample set deviating from Hardy-Weinberg expectations was highly significant with all loci included (Table 1). As the number of loci and their level of polymorphism were limited, analyses could not be run with and without loci suspected of having null alleles.

The pairwise comparison of the FST values (measured as Weir and Cockerham's Θ) were all very small (Table 2). Of these values, only one was significant, the Sambro and Upper Bay of Fundy samples ($P=0.01646\pm0.0019$). This is the only significant difference seen in this sample set.

This study did not find evidence of dogfish population structuring in Canadian waters based on the loci used. However, it is possible that a larger sample size and a larger number of polymorphic loci, or sampling of mating aggregations, would have detected population structuring. U.S. samples will be analyzed for differences from the Canadian samples when they become available.

Tagging Studies

Several studies have been published which report on recapture and movement of tagged spiny dogfish in the northwest Atlantic. However, there have been significant numbers of recaptures post-publication, plus two studies which have never been published. To this point, no one has attempted to summarize these various studies in a single analysis. To do so, we start by presenting tagging and recapture locations for each study individually (including any unpublished results), then analyzing all of the studies together.

Templeman (1954, 1984) tagged 2657 dogfish at various inshore and offshore locations in southern Newfoundland between 1942 and 1965 (Table 3). Of the 232 recaptures, 216 were recaptured in Newfoundland waters, 12 were caught around NS or NB, and 4 were caught in U.S.

waters (Fig. 9). An addition, Templeman (1976) reported that two tagged dogfish made trans-Atlantic migrations, one to Iceland and one to Scotland.

Moore (1998) tagged 995 dogfish in the Minas Basin of the Bay of Fundy (Canada) in 1996. There were 39 recaptures from this study, 21 of which were reported in Moore (1998), and 18 of which are reported here for the first time (Table 3). Many of the recaptures were made many years after release. Of these recaptures, 29 were made in Nova Scotian waters, and 10 were in and around Cape Cod (USA) (Fig. 10).

Register (unpublished) tagged 743 dogfish in the Bay of Fundy in 2005-2006, recapturing 10, all in Canadian waters (Table 3; Fig. 11). Of the 10 recaptures, 8 were in the Bay of Fundy and 2 were off of southern Newfoundland.

Jensen (1961, 1966, 1969) tagged 999 dogfish at 4 sites in northeastern U.S. waters between 1956 and 1961 (Table 3). A total of 25 recaptures were made, most of which were in the northeastern U.S. and 2 of which were in southwestern N.S. (Fig. 12). He also tagged an additional 50 fish on Browns Bank (Canada), obtaining 2 recaptures in Canada.

Myklevoll (1993) tagged 500 dogfish on Georges Bank (U.S.) in 1968 (Table 3), but few North Americans are aware of this publication written in Norwegian. There were 14 recaptures, 11 of which were in U.S. waters as far south as North Carolina, and 3 recaptures in southwest N.S. (Fig. 13).

Shafer (1970) tagged 649 dogfish off North Carolina in 1967, and an additional 2934 dogfish in northeastern U.S. waters between 1966 and 1969 (Table 3). Of the 60 recaptures, 53 were made along eastern seaboard of the U.S. and 7 were in southwest N.S. (Fig. 14).

In the largest study of its kind, Rulifson (unpublished) tagged 36,604 dogfish in North Carolina waters between 1997 and 2006 (Table 3). Of the 285 recaptures, 269 were made along the eastern seaboard of the U.S. (many in the northeastern U.S.) and 16 were made off southwestern N.S. (Fig. 15).

A visual synthesis of all of the tagging studies except those of Rulifson (unpublished) is shown in Fig. 16. In all, over 46,000 dogfish have been tagged, with 667 recaptures. For the most part, dogfish tagged in Canadian waters remained in Canadian waters, and those tagged in U.S. waters remained in U.S. waters. However, there was clearly some movement between countries, with the Gulf of Maine region being the primary mixing ground. Overall, 346 of 384 (=90%) of recaptures from U.S. tagging sites were recaptured in U.S waters, and 267 of 283 (=94%) recaptures from Canadian tagging sites were recaptured in Canadian waters (Table 3). Restricting the analysis to the Gulf of Maine, 75/86 (=87%) of U.S. tagged fish and 41/51 (=80%) of Canadian tagged fish remained within their host country (Table 3). A more rigorous analysis of tag movements would weight recaptures by fishing effort. Although fishing effort data for all but the recent studies were unavailable, an attempt was made to weight by a proxy for effort: catch. However, catch weighting was confounded by huge landings by foreign fleets in unknown waters (Table 3). In the one study where proper catch weighting was possible (Moore 1998), the analysis reinforced perceptions that most tagged dogfish remained in their host country.

To test the hypothesis that large-scale or trans-boundary migrations are limited to mature females, we tested for sex-specific differences in distance of recapture from tagging site or cross-border movement. Unfortunately, virtually all dogfish tagged in all studies were large females. We noted that none of Shafer's 12 recaptured males (out of 160 tagged) migrated to Canada, but the

difference from females was not significant (chi-square test, $P > 0.1$). Similarly, the fact that only one of Rulifson's (unpublished) 13 recaptured males was recaptured in Canada was not significant ($P > 0.1$). Nor did any of the tagging studies that presented information on sex and length at tagging and recapture (Moore 1998; Register unpublished; Rulifson unpublished) show a significant relationship between length of dogfish and distance of migration ($P > 0.1$). Although these results suggest that there is no evidence that migration is linked to large (mature female) dogfish, the statistical power of the test was weak.

An analysis of each of the individual tagging studies indicated a strong seasonal pattern in direction of movement, particularly among dogfish south of the Gulf of Maine. In most studies, dogfish tended to be recaptured in more northerly waters in the summer, peaking in August (Fig. 17). To some extent, this pattern is forced by spatial patterns in fishing effort, since there is little or no fishing for dogfish in winter months in northerly waters, and thus no recaptures are possible there during the winter. Nevertheless, the fish tagged in North Carolina waters (Rulifson unpublished) clearly migrated north to the southern Gulf of Maine during the spring and returned in late fall, given that there were few recaptures in southerly waters during the summer (Fig. 17).

In summary, analysis of all available dogfish tagging data supports the view that there are several non-independent dogfish stock components in the northwest Atlantic. Dogfish movements between Canadian and American waters are not the predominant pattern, accounting for only 10-20% of tag recaptures.. Large-scale annual migrations occur along the east coast of the U.S., but are primarily limited to the area between North Carolina and the Gulf of Maine. Cross-border mixing does occur, but its extent (10% on average) is on the same scale as that observed with groundfish stocks such as 4X cod. Therefore, there appears to be both migratory and resident components, as Templeman (1976) hypothesized for Newfoundland dogfish populations.

To determine if a mix of migratory and non-migratory components is consistent with other spiny dogfish populations around the world, the published literature from the well-studied British Columbia and European populations was reviewed. After tagging >70,000 dogfish in BC, McFarlane and King (2003) reported that the majority of recaptures were made close to the release site; however extensive migrations did occur, including across the Pacific Ocean. About 85% of the coastal dogfish stayed in the Strait of Georgia, apparently forming a non-migratory component, but most of those tagged offshore or in northern BC migrated considerable distances. Interpretations were less clear in European waters, but Vince (1991) and other European studies reported significant movements throughout and around the North Sea, including one trans-Atlantic migration (Holden 1967).

An important question remains though: do dogfish move south to U.S. waters each fall to overwinter, then return to Canadian waters each spring? The next section will test this hypothesis by examining evidence of dogfish overwintering in Canadian waters.

Seasonal Migrations in Canada: Inshore/Offshore or North/South?

If dogfish migrate south out of Canadian waters each year, the migration should be evident in terms of reduced winter/spring biomass prior to the return migration. There are only a few areas and periods where matching seasonal RV surveys exist, and these will be examined in turn.

Fig. 18 compares the RV survey distribution of dogfish between summer and early spring on the Scotian Shelf, southern Gulf of St Lawrence and off southern Newfoundland. The same period (1979-1984) was used throughout, although dogfish had not yet arrived in the southern Gulf of St Lawrence by 1984, so the 1985 4T distribution was used instead. Note that coverage of 3Ps in

the Newfoundland fall RV survey was minimal. Summer distributions tended to be throughout coastal waters, including on shallow banks (Fig. 18). In contrast, spring distributions were almost entirely in deep basins and off the edge of the continental shelf. In all areas, spring distributions were further offshore (or deeper) than summer distributions, with no evidence of net migration out of the area. Indeed, spring biomass was consistently greater than that in the summer (see legend, Fig. 18). This perception was confirmed by comparing the total stratified abundance and biomass of the spring and summer RV surveys in 4VWX. The summer biomass ranged between 20,000-95,000 mt annually while the spring biomass ranged between 53,000-344,000 mt (Table 4). In all years, spring abundance and biomass exceeded summer abundance and biomass by an average of 2-5 (Table 4).

A similar pattern of higher winter/spring abundance and biomass, and no evidence of migration to other areas, was observed in other regions. A comparison of 4VW spring and summer RV surveys demonstrated that spring abundance and biomass exceeded that of summer by a mean factor of 26-58 (Table 5). The higher biomass ratio in the spring survey was particularly accented in the high-abundance years prior to 1992, but spring biomass continued to match or exceed summer biomass in low-abundance years as well.

There was no evidence that spring biomass on the Scotian Shelf was high due to overwintering of dogfish from Newfoundland. A comparison of spring vs fall abundance in NAFO 3LNO indicated parity between the two surveys (Table 6). Since most of the dogfish in Newfoundland waters in spring are found in 3Ps (Table 11 of WP 2007/29), it is possible that spring biomass in Newfoundland waters would also have exceeded that in the fall, but fall RV surveys of 3Ps are not carried out.

The analysis of seasonal RV surveys in Canadian waters described above do not support the hypothesis that dogfish move south out of Canadian waters for the winter. Indeed, the higher stratified abundance and biomass in the early spring surveys suggests that additional fish have appeared from somewhere else. Could they have moved north from U.S. waters? A comparison of spring versus fall RV surveys indicates that spring abundance and biomass in U.S. waters exceeds that in the fall by an average factor of 2.7 (Table 7), comparable to what was observed in Canadian waters. In the past, some have interpreted the greater abundance in the U.S. spring RV survey compared to their fall RV survey as evidence of additional overwintering fish which had migrated in from Canada. Our results reject this interpretation. In other words, spring biomass appears to be higher in both Canadian and U.S. waters. Since it is obvious that fish cannot appear out of nowhere, the apparent increase in spring biomass must be due to a change in catchability. That is, spring aggregations of dogfish in deeper, offshore waters must be easier to catch in the RV gear, perhaps due to the position of dogfish in the water column or lower swimming speed. A more likely explanation is that a significant proportion of the summer distribution is concentrated in shallow nearshore waters not surveyed by the RV gear. Whatever the cause, the fact that catchability increases by a comparable factor between Canadian and U.S. waters suggests that there is little in the way of net southern migration out of Canada for the winter. Seasonal migrations appear to be exclusively (or at least mostly) inshore-offshore.

A comparison of the length composition between the seasonal RV surveys provides some insight into the nature of the early spring aggregations offshore. The sex-specific size compositions of the summer (July) and fall (Oct-Nov) RV surveys between 1979-1984 are very similar, indicating that there is no appreciable sex- or size-specific migration out of the survey area before mid-fall (Fig. 19). In contrast, there are large and significant differences between the sex-specific length compositions between spring and summer, such that large males and in particular large mature females are much more represented in the offshore spring aggregations. Thus it seems likely that

these spring aggregations are mating or pupping aggregations. The fact that the offshore spring aggregations comprise both sexes suggests that they may be mating aggregations (Fig. 20).

An analogous comparison of length compositions on the eastern Scotian Shelf (NAFO 4VW) during years of high dogfish abundance (1986-1991) shows a similar pattern with respect to the females: many more large mature females were present in the spring survey than in the summer survey (Fig. 21). Interestingly however, modes corresponding to young juveniles were evident in the summer survey, but not in the spring survey. If those juveniles were indeed present in the spring, their catchability must have been very low. An alternative explanation is that they migrated onto the Scotian Shelf from U.S. waters for the summer, then returned before winter.

The length composition of the eastern Scotian Shelf (NAFO 4VW) during years of low dogfish abundance (1994-2003) presented a somewhat different pattern (Fig. 22). In those years, the relative abundance of young males was higher in the spring than in the summer, while that of young females was spread over a greater size range. In keeping with the other analyses though, large mature females were relatively more abundant in the spring compared to the summer.

The fact that spring RV surveys in various regions consistently catch more large females than are captured in the summer can only be explained by one of three possible mechanisms:

1) Mature females present in offshore waters in spring subsequently migrate south out of Canadian waters into U.S. waters before the time of the summer survey. This option does not seem likely since it would require a southward migration in the late spring, when all available tagging and migration data suggests that migration should be northward at that time of year.

2) Mature females arrive offshore in Canadian waters in fall or winter from somewhere other than inshore waters. This option also does not seem likely, since it would require either a northward migration from the U.S. in the fall (when all known migration is proceeding southward) or a southward migration from more northerly waters (where there is no evidence of large-scale migration at all).

3) Mature females are not really more abundant compared to smaller dogfish in the spring. Rather, their catchability is higher in the spring, or to turn it around, their catchability is low in the summer. This hypothesis seems most likely. A comparison of the summer RV size composition in 4X for the years 2002-2006 with that of commercial longline and gillnet catches over the the same time period in the same area indicates that the summer RV catches relatively few (< 5%) females of mature size (Fig. 23). In contrast, the catch of mature females in commercial gear exceeds 45% of the catch numbers. Therefore, the mature females are definitely there in the summer; they're just not easily caught or available to the RV otter trawl gear. Consistent with this hypothesis are observations by fishermen and others (Moore 1996) that large females are most common inshore in shallow regions not surveyed by research vessels, such as the upper Bay of Fundy.

To summarize, all evidence indicates that spring RV surveys provide the best available view of the dogfish size distribution, and that mature females are too far inshore during the summer to be adequately surveyed by the RV gear. Alternative explanations for the apparently increased abundance of mature females during the spring, and their absence during the summer, are not viable. Summer RV surveys demonstrate that the mature females do not show up further north. And tagging results indicate that they do not move south in the late spring. Therefore, it seems most reasonable to accept that the relatively high biomasses estimated by RV surveys in the spring are due to high catchabilities, and that the spring catchability of large females is enhanced

over that of smaller dogfish. The conclusion is that spring RV surveys are a better representation of sub-adult and adult abundance than are summer RV surveys. Thus large females remain on the Scotian Shelf throughout the year, moving well inshore during the summer and offshore during the fall and winter.

Dogfish as a Metapopulation

A metapopulation can be defined as a group of spatially separated groups or populations of the same species which interacts at some level. Range expansions can bring one group into contact with another, or re-populate areas vacated by another group. As a result, periodic mixing can prevent the development of genetic differences. Although it is not clear that spiny dogfish fit the exact definition of a metapopulation, there do appear to be some characteristics in common:

- There are several more or less well-defined 'groups' of dogfish, such as those occupying the southern Gulf of St Lawrence, around Newfoundland, the eastern and central Scotian Shelf, Bay of Fundy and SW Nova Scotia, Massachusetts and North Carolina.
- The groups remain largely separate, and engage in seasonal onshore-offshore migrations. Some groups undertake seasonal north-south migrations, particularly those in the south. The migrations may be an evolutionary adaptation to remain in a "preferred" temperature range of 5-12 degrees C throughout the year.
- There is occasional mixing between groups, particularly those in the Gulf of Maine.
- Although genetic studies are incomplete, there are unlikely to be genetic differences among groups.
- At least one of the groups – that in the southern Gulf of St Lawrence – is almost certainly a "sink" population. That is, it was colonized abruptly in 1985, and the same group has resided there ever since, growing larger in size but smaller in numbers, with no evidence of outside immigration or recruitment. The mean length in the population increased by an average of 0.47 cm/yr (SE=0.02) between 1985 and 2002, slightly less than the growth rate of 1.22 cm/yr expected of 4X dogfish of comparable size. It seems likely that the generally cooler water temperatures present in the Gulf would have slowed growth compared to 4X, in which case the observed increase in size may be explicable solely on the basis of growth.
- The Eastern Shelf dogfish component appears to have remained resident for many years in NAFO 4VW, then abruptly disappeared in 1992. At around the same time, the Georges Bank component disappeared. These dogfish, whose minimum trawlable biomass was about 300,000 mt, apparently moved to another area, since the abrupt decline cannot be explained by fishing or discarding.

A spiny dogfish metapopulation presents some interesting implications for fisheries management. First of all, it would suggest that Canadian dogfish cannot be viewed in isolation. At a minimum, if some of the dogfish that currently reside in Canadian waters actually originated in U.S. waters, it means that at least some of the recruitment is dependant on the U.S. stock. Secondly, the existence of a metapopulation would imply that managing North American dogfish as a single stock would be inappropriate. If, as seems likely, some dogfish aggregations colonize or depart Canadian waters *en masse* at periodic multi-year intervals, and then remain resident in those waters for many years at a time, alternate management strategies may be more appropriate. Finally, without knowing the extent that Canadian spawners contribute to the health of the northwest Atlantic dogfish metapopulation, it is possible that a fishery on mature females in either Canadian or U.S. waters could impact the abundance in all areas.

The Fishery

Landings

The fishery for spiny dogfish in the Northwest Atlantic began long before commercial catch statistics came to be reported. Reported landings prior to extension of jurisdiction in 1977 were dominated by USSR (Russia) and other European countries, and peaked at about 25,000 mt annually (Table 8; Fig 24). Unfortunately, the country where fishing took place was not recorded. After 1977, U.S. commercial landings accounted for most of the reported catch, peaking at more than 27,000 mt annually. Canadian landings have been a relatively small proportion of the total catch until 2000, at which point the introduction of quotas in the U.S. made Canadian landings a significant portion of the total (Table 8).

Canadian landings have averaged about 2500 mt annually since 2000, with the majority of that being directed catch by handline and longline, followed by gillnets (Table 9). The vast majority of landings were reported from Nova Scotia (Table 10). Almost all of the dogfish were caught in the Bay of Fundy, southwest Nova Scotia and off Halifax (Fig. 25). Summer is the principle time for dogfish fishing (Fig. 26). Although incidental landings have been reported by several fleets, the only gear sector responsible for a significant proportion of Canadian landings other than longlines/handlines has been by gillnets (Table 9). Catches were unrestricted prior to 2002. From 2002 onwards, precautionary directed catch quotas based on past catches were put in place. The 2002 quota of 3200 mt was exceeded by 384 mt, but directed catches in subsequent years have not exceeded the quota (Table 9). The quota since 2004 has been set at 2500 mt. Quotas to this point have not been based on scientific advice. There are no restrictions on discarding and bycatch in other fisheries.

Discards

Unintended and unwanted bycatch of dogfish by Canadian fisheries is substantial, and has achieved an almost legendary status over the years. To quantify the bycatch, observer records of dogfish catch relative to target catch were calculated by fishery, NAFO area, season and year. Observer coverage varied among regions, years and fisheries, but averaged 12% (Table 11). The proportion of dogfish in each observer cell was then multiplied by the total reported landings (from ZIF until 2002, and from MARFIS and other regional statistics after 2002) of the target catch in each cell to obtain the estimated dogfish catch in each cell. The resulting dogfish bycatch by fishery and NAFO area, aggregated by year, varied widely among gear sectors and areas (Table 12). The largest bycatch was associated with the groundfish (OTB, LL, gillnet) and OTB redfish fleets in 4X5Y, although all areas and most fleets reported large dogfish bycatches at some times (Fig. 27). Total discards have averaged 2,000-3,000 mt annually in recent years, although discards of up to 10,000 mt were estimated for some years in the 1990s (Table 12).

Spiny dogfish are relatively hardy, so it is only reasonable to assume that discard mortality is not 100%. Unfortunately, there are few available estimates for dogfish discarding mortality. Revill et al. (2005) reported 2% mortality for OTB-caught lesser-spotted dogfish (*Scyliorhinus canicula*), although Rodriguez-Cabello et al (2005) reported 22% mortality for the same species under more rigorous experimental conditions. Mandelman and Farrington (2007) reported a maximum of 29% mortality for discarded spiny dogfish, but their results were confounded by a relatively high mortality in their control fish. Nevertheless, they suggested that mortality in large tows (>200 kg) would be expected to be even higher. The best available discard mortality estimates come from Rulifson (2007), who reported a 55% mortality rate for dogfish caught in gillnets, and 0% for small numbers caught in otter trawls. All of these mortality estimates are

considerably different than are assumed by than are assumed by the U.S. National Marine Fisheries Service, who used estimates of 50% for OTB discards and 30% for gillnets (NFSC 2006). The basis for the U.S. estimates are unclear.

Dogfish discard mortality in Canadian waters was calculated as per the following: 25% for OTB catches > 200 kg, 0% for OTB catches < 200 kg, 55% for gillnet catches, 10% for longline catches, and 25% for purse seine catches. The exact values are debatable, although all appear to be consistent with the experimental values reported above and observer observations of the manner in which fishers and their gear treat dogfish catch. To estimate the proportion of the OTB catches which exceeded 200 kg, observer data in 4X5Y for the years 2002-2006 were analyzed. Of the OTB redfish sets, 66% of the sets but only 5.4% of the landed catch was less than 200 kg. For silver hake OTB, 10% of the sets but only 0.1% of the landed catch was less than 200 kg. For groundfish OTB, 77% of the sets corresponding to 15% of the landed catch was less than 200 kg. Therefore, these proportions were those that were used in the discard mortality calculations of Table 12.

Estimated dogfish discard mortality has averaged about 850 mt annually since 1986 (Table 12). Discard mortality often exceeded reported catch prior to 1999, but recent landings have greatly exceeded discard mortality (Table 12; Fig 28).

Age and Size Composition of the Commercial Catch

The length composition of the commercial catch over the years 2002-2006 in 4X indicated that females ranged in length from 46-112 cm total length (TL), while males ranged from 36-94 cm (Fig. 29). Most of the catch was of sub-adult and adult size. Median size of females in the catch was 81 cm TL, while that of males was 74 cm. In terms of catch numbers, 66% consisted of females, and 26% of the catch consisted of mature females. These numbers are much lower than those present in the U.S. commercial catch, where median body size of females in the catch was 86 cm TL and females made up 91% of the catch numbers between 2002-2005 (NFSC 2006).

There are some markets where large dogfish are valued more highly than smaller dogfish. In order to test if this preference might have encouraged 'highgrading' at sea (discarding smaller dogfish in preference for larger dogfish), the size composition of the at-sea and landed catch was compared for each of the two major gear types (longline/handline and gillnets) in each of two years (Fig. 30). Landed dogfish were not significantly larger than at-sea (pre-discarding) dogfish, indicating that any highgrading of the catch would have to have been of small scale.

Dogfish in the commercial catch tended to be fairly old, with a mean age of 16 yr for males (n=450) and 18 yr for females (n=1085) (Fig. 31).

Abundance Indices

There are a number of RV surveys and industry surveys in Atlantic Canada that catch significant numbers of dogfish. Although these surveys together do not cover the entire range of spiny dogfish, they can be used to provide an index of relative abundance across years. In this section, the distribution, size composition (where available) and relative abundance of dogfish in each of these surveys is considered in turn. Where possible, relative abundance has been calculated in terms of minimum trawlable biomass so as to allow comparison of relative biomasses among regions. However, differences in gear catchability between surveys may scale the total biomasses differently.

The July RV survey of the Scotian Shelf shows no obvious changes in dogfish distribution or size composition between 1970 and 2006 (Figs. 32 and 33). In contrast, overall abundance increased markedly after 1984 and has remained high, albeit variable, to the present (Table 13; Fig. 34). Note that in the absence of information to the contrary, the catchability of the Western IIA survey gear being towed by the RV Needler has been considered equivalent to that of the same survey gear being towed by the RV Teleost (2004, 2006).

Spring (Mar-Apr) RV surveys of the Scotian Shelf were carried for 5 years between 1979-1984 as part of a seasonal comparison. The spring RV distribution was centred offshore and in deeper waters than was the summer RV distribution (Fig. 35). Size composition and relative abundance varied significantly across years, with no obvious trend (Table 14; Fig. 35).

Fall (Oct-Nov) RV surveys of the Scotian Shelf were carried out for 6 years between 1978-1984 as part of a seasonal comparison. The fall RV distribution was similar to that of the summer distribution (Fig. 36). There was no apparent trend in size composition, and relative abundance fluctuated, with a strong increase in the last year (Table 14; Fig. 36).

March RV surveys for 4VW cod also also collected information on dogfish since 1986. Dogfish distribution in the 4VW cod survey was centred offshore and in the deeper basins of the Scotian Shelf (Fig. 37). The size composition has been variable, but has tended to be dominated by larger fish (Fig. 38). Relative abundance remained high but variable until 1992, after which it dropped abruptly to about 15% of its previous level (Table 15; Fig. 38).

February surveys of Georges Bank have been conducted since 1986. Dogfish distribution at that time of the year is concentrated at the edge of the bank in deeper water (Fig. 39). Size composition has varied over the years, but has sometimes shown a bimodal distribution corresponding to small juveniles and mature adults (Fig. 40). Relative abundance peaked in 1993, then declined abruptly to very low levels, where it has remained since (Table 16; Fig. 40).

Deepwater surveys for redfish on the Scotian Slope were the only survey of this area in the fall (Oct-Nov) (Fig. 41). However, despite their abundance in this same area during the spring, dogfish were seldom caught in this survey between 1982-1988, and those that were caught were of sub-adult size.

The 4VsW cod sentinel longline survey operated each fall (Sept-Oct) between 1995-2005. Dogfish were caught throughout the survey area, although they tended to be uncommon on the shallow offshore banks (Fig. 42). There was no obvious trend in the size distribution across years, although relative abundance declined through the time series (Table 17; Fig. 42).

Longline surveys for halibut have been conducted on the Scotian Shelf and off southern Newfoundland each June since 1998. Dogfish have been caught throughout the survey area, but have been much more concentrated off central and southern Nova Scotia (Fig. 43). Length frequency data were not collected. Relative abundance in this series has been variable, but has increased (Table 17; Fig. 43).

Sentinel longline surveys for 4Vn cod were carried out in 4Vn during September each year between 1994 and 2001. Dogfish were collected throughout the survey area (Fig. 44). No length frequencies were recorded. Relative abundance declined markedly after 1994 and never recovered (Table 17; Fig. 44).

September groundfish RV surveys of the southern Gulf of St Lawrence recorded no spiny dogfish whatsoever between 1971-1983. Once they appeared, they became widely distributed near shore and along the edge of the Laurentian Channel (Fig. 45). The size distribution was uni-modal, and increased gradually in modal length across years, consistent with the increase expected of growth (Fig. 46a). The mean length in the population increased by an average of 0.47 cm/yr (SE=0.02) between 1985 and 2002, slightly less than the growth rate of 1.22 cm/yr expected of 4X dogfish of comparable size, but consistent with the generally cooler water temperatures present in the Gulf which would have slowed growth compared to 4X (Fig. 46b). Relative abundance was greatest in the 1980s and has declined ever since (Table 18; Fig. 45). The sudden appearance, progressive increase in size composition, and gradual decline in abundance are all consistent with that of a 'sink population' – a pulse of dogfish that arrives from somewhere else, then never leaves. The subsequent presence of dogfish in the deep warmer waters of the Laurentian Channel in January RV surveys confirms that at least some of the dogfish remained resident all year round (Fig. 47).

Spiny dogfish have been collected in summer RV surveys of the northern Gulf of St. Lawrence. However, analysis of these data indicated that there were substantial numbers of records for dogfish < 20 cm TL, which is below the birth length. Since black dogfish (*Centroscyllium fabricii*) are common in the northern Gulf, it appears likely that at least some of the spiny dogfish records are actually black dogfish. Accordingly, these data were not considered further.

Spring (Feb-May) RV surveys of southern Newfoundland (NAFO 3LNOP) have been carried out each year since 1972. Dogfish distribution at that time of year is concentrated in the deeper waters at the edge of the Laurentian Channel and continental shelf (Fig. 48). Size frequency data were not collected. Relative abundance between 1972-2005 has been variable with no obvious trend (Table 19; Fig. 48).

A comparison of minimum trawlable biomasses from all Atlantic Canadian RV surveys gives a relative indication of the stock proportion present in each area (Fig. 49). Given the large differences in RV catchability between spring and summer, it is appropriate to compare trawlable biomass only within a given season. The comparison of the various summer/fall RV surveys (summer 4VWX5Z, fall 4VWX and 4T) indicates that the fall and summer trawlable biomasses are roughly comparable, and show similar trends. However, the trawlable biomass in the southern Gulf of St Lawrence is roughly 10% of that on the Scotian Shelf, and thus is small by comparison.

A comparison of the spring RV surveys shows that the spring 4VWX, spring 4VW and the Feb Georges Bank trawlable biomasses are all comparable, although the spring 4VWX survey does not overlap in time with any other spring survey (Fig. 49). Interestingly, the abrupt decline in the 4VW spring survey in 1993 occurred one year after an abrupt increase in the Georges Bank survey, but 1-2 yr before the abrupt decline on Georges. Thus there was no obvious link between areas in the changing abundances. Nor was there any apparent change in the summer 4X biomass in or around 1993, indicating that the 4VW dogfish did not migrate to 4X. The trawlable biomass in Newfoundland waters was negligible compared to the other regions prior to 1997, but the biomass in the other regions subsequently declined so that the Newfoundland biomass is now comparable.

A comparison of the relative abundance indices among the various industry surveys (included both longline and mobile gear surveys) provides no strong insights and therefore was not used (Table 18; Fig. 50).

In light of the differing seasons for RV surveys across regions in Atlantic Canada, it is difficult to prepare a single within-season index that covers all regions and time periods. Nevertheless, an approximation was prepared. A spring estimate of minimum trawlable biomass was calculated by summing the biomasses from the February Georges (1986 onwards), spring 4VWX (1979-1984 only), March 4VW (1986 onwards) and spring Newfoundland surveys. Aside from gaps prior to 1979 and in 1985, the glaring problem with this estimate is the absence of any spring survey value from 4X after 1984. Given that 4X accounts for most of the dogfish in Atlantic Canada, any viable Canadian spring index must contain a value for 4X in spring. As a proxy value for spring 4X, we used the dogfish biomass in 4X (only) from the summer RV survey for 1985 onwards. By doing so, we have necessarily assumed that summer 4X biomass is comparable to spring 4X biomass. We were able to test this assumption by comparing spring and fall 4X biomasses between 1979-1984, when seasonal surveys were available. On average, spring 4X biomass exceeded summer 4X biomass by a factor of 3.8, while spring 4X abundance exceeded summer 4X abundance by a factor of 2. Therefore, it seems reasonable to conclude that use of summer 4X biomass as a proxy for spring 4X biomass would, if anything, result in a conservative estimate of total biomass. Accordingly, our estimate of total Atlantic dogfish spring trawlable biomass is the sum of the biomasses from the February Georges (1986 onwards), spring 4VWX (1979-1984 only), March 4VW (1986 onwards), spring Newfoundland, and summer 4X (1985 onwards) surveys. This index does not include estimates from 4T, and is probably a gross underestimate for years prior to 1979. However, it probably provides a reasonable approximation of the minimum trawlable adult biomass summed across areas.

The estimate of summer minimum trawlable biomass in Canadian waters was calculated as the sum of the summer 4VWX5Z and 4T surveys. Therefore, the index does not include an estimate for Newfoundland waters, for which no RV survey is available for the 3Ps area most populated by dogfish. Since the summer RV surveys do not adequately represent the abundance of mature females, the summer index is probably a better representation of sub-adult biomass than adult biomass.

A comparison of the spring minimum trawlable biomass between Canadian and U.S. waters is shown in Fig. 51. Neither of these indices is completely accurate, since the U.S. surveys cover parts of NAFO 4X and the Canadian side of Georges Bank, while the Canadian index includes the U.S. side of Georges Bank. To a rough approximation, these two biases may cancel each other out. Both time series show comparable trends, increasing from the early 1980s to the early 1990s, then declining somewhat to the present. Mean values for both indices were around 500,000 mt in the early 1990s, declining to about 300,000 mt in 2007 for the Canadian index. Across the time series as a whole, the U.S. minimum trawlable biomass estimate (NFSC 2006) has been slightly greater than the Canadian minimum trawlable biomass estimate.

The summer/fall minimum trawlable biomass trends for both countries are more variable than are those from the spring (Fig. 51). Both indices show a consistent upward or stable trend from about 1985 to the present. Once again, the U.S. minimum trawlable biomass estimate slightly exceeds the Canadian estimate. The most recent Canadian biomass value is about 350,000 mt, corresponding to about 200 million fish.

A preliminary calculation of overall mature female biomass for Canadian waters was calculated as the sum of the mature female biomasses from the February Georges (1986 onwards), spring 4VWX (1979-1984 only), March 4VW (1986 onwards), spring Newfoundland, and summer 4X (1985 onwards) surveys, thus requiring the same assumption as that required of the total biomass calculation. To test the assumption that 4X summer mature female biomass is comparable to that of spring 4X, two tests were done. In the first test, mature female biomass in 4X was compared

between spring and summer in the period 1979-1984, when seasonal surveys were available. Mature female biomass in the spring exceeded that in the summer by an average of 10X. As a second test, we compared spring and summer mature female biomass in 4VW for periods of high (before 1992) and low (after 1992) dogfish abundance. For the period of high dogfish abundance, spring mature female biomass greatly exceeded (~50X) that present in the summer. However, during the period of low abundance, the spring:summer mature female biomass ratio was ~1:1. Given all of these results, we concluded that use of summer 4X summer mature female biomass as a proxy for spring 4X could underestimate actual spring biomass by a very large amount, and thus should not be used. In addition, values for 4T and 3LNOP were not available due to absence of spring surveys (4T) and length frequency data (3LNOP).

Mature female biomass in the various spring RV surveys generally exceeded 25,000 mt in the 1980s, but has declined to lower values in recent years (Table 20). A comparison of U.S. and Canadian mature female biomass across years was not possible because of the unavailability of a spring 4X mature female biomass index. In addition, the U.S. index is based on females > 80 cm total length, while the Canadian indices are based on 82+ cm. However, mature female biomass in the U.S. spring RV survey has declined to much lower values in recent years, albeit with an upturn in the last two years (NFSC 2006; Fig. 52). Without knowing the extent that Canadian spawners contribute to the health of NW Atlantic dogfish metapopulation, it may not be wise to increase the exploitation rate on mature females.

It was not possible to estimate exploitation rate in the absence of a viable population model. However, it did not appear that the apparent recent decline in total Canadian spring biomass can be attributed solely to commercial exploitation (Fig. 51). Total catch (including dead discards) between 1990 and 2006 accounted for about 3,000 mt per year, while the apparent decline in total biomass was closer to 18,000 mt per year. It is unknown if this is an actual loss to the population, and if a loss, if it was temporary or permanent. Emigration to unsurveyed areas and/or unexplained natural mortality could account for this loss, among other factors.

Population Model

A preliminary population model has been developed for dogfish (Appendix 1). This model is an age- and sex-structured, forward projecting population model, which estimates a starting population size and age structure (in 1960), and projects the population forward by adding recruits (age-1 fish) to the population and subtracting catches and natural mortality. Both foreign and domestic landings are included in the model. The model is fit to the abundance indices obtained from research surveys as well as the proportions-at-length in the surveys and commercial catch. Some of the data series used in the model are short and highly variable, and although the summer RV survey potentially indicates a stable or slightly increasing population, some of the other surveys indicate a declining trend. As a result, the model in its present form does not provide robust estimates of abundance. Three variants of the model were used to estimate abundance, each with a different assumed reproductive scenario. The variants were fit to the summer RV survey data alone, and in another iteration to six research surveys. These variants illustrated several problems with the model in its present form, including several aspects of the fishery, dogfish biology and/or data collection process that are not adequately captured. Recommendations for the next iteration of the model included a recompilation of the commercial catch and survey data on the same spatial scale so that spatial structuring within the population and movement can be examined, further separation of the two sexes in the model, examination of sample sizes to ensure that data is weighted appropriately, and further development of a relationship between variability of length-at-age and age. If possible, immigration and emigration

should be incorporated. Robustness of the model estimates with respect to the length of the time series incorporated into the model should also be examined.

Sources of Uncertainty

There is uncertainty surrounding the conclusions of the genetic analysis of spiny dogfish conducted to date at the Bedford Institute of Oceanography. Small sample size, the number of polymorphic loci, and lack of samples from mating aggregations contribute to uncertainty. Lack of U.S. samples is an additional source of uncertainty.

Surveys do not cover the entire range of spiny dogfish in Atlantic Canada. In particular, lack of a spring RV survey in 4X and summer surveys in inshore areas and the upper Bay of Fundy hampers calculations of mature female biomass.

The accuracy of some historic foreign landings has been questioned. The size composition of foreign landings was not reported.

Tagging of males and juveniles has been limited. Limited Canadian fishing effort in winter months complicates the interpretation of winter recaptures.

Bycatch and discarding estimates were based on observer coverage that was limited or absent in some fisheries and years, for which mean values from adjacent years were used. This undoubtedly introduced some error into the discarding estimates.

Some observations from the fishing industry indicate that there might be large females that remain in the Bay of Fundy throughout the winter. This needs to be explored.

Spiny dogfish have been collected in the northern Gulf of St. Lawrence by RV surveys, but the likely presence of black dogfish in amongst the spiny dogfish records confounded attempts to prepare an abundance index for the region.

Conclusions and Advice

For the most part, dogfish tagged in Canadian waters have remained in Canadian waters, and those tagged in U.S. waters have remained in U.S. waters. However, there is some movement (10-20%) between Canadian and U.S. waters, with the Gulf of Maine region being the primary mixing ground. To date, there has been no evidence that migration is associated with a particular sex or size of dogfish.

Spiny dogfish have many characteristics of a metapopulation, and thus presents some interesting implications for fisheries management. First of all, it would suggest that Canadian dogfish cannot be viewed in isolation. At a minimum, if some of the dogfish that currently reside in Canadian waters actually originated in U.S. waters, it means that at least some of the recruitment is dependent on the U.S. stock. Secondly, the existence of a metapopulation would imply that managing northwest Atlantic dogfish as a single stock would be inappropriate. If, as seems likely, some dogfish aggregations colonize or depart Canadian waters *en masse* at periodic multi-year intervals, and then remain resident in those waters for many years at a time, alternate management measures may be more appropriate. Finally, without knowing the extent that Canadian spawners contribute to the health of the northwest Atlantic dogfish metapopulation, it is possible that a fishery on mature females in either Canadian or U.S. waters could impact the abundance in all areas.

Based on analysis to date, median size of females in the catch was found to be 81 cm TL, while that of males was 74 cm TL. In terms of numbers, 66% of the catch consisted of females and 26% consisted of mature females. These numbers are much lower than those present in the U.S. commercial catch, where median body size of females in the catch was 86 cm TL and females made up 91% of the catch numbers between 2002-2005. Dogfish in the Canadian commercial catch tended to be fairly old, with a mean age of 16 years for males and 18 years for females. There was no evidence of "highgrading" at sea.

Estimated dogfish discard mortality has averaged about 850 mt annually since 1986. Discard mortality often exceeded reported catch prior to 1999, but recent landings have greatly exceeded discard mortality.

In the absence of a viable population model, it is not possible to estimate the exploitation rate for spiny dogfish in Atlantic Canada. However, it does not appear that the apparent decline in total Canadian spring biomass can be attributed solely to commercial exploitation. Total catch (including dead discards) between 1990 and 2006 accounted for about 3,000 mt per year, while the apparent decline in total biomass was closer to 18,000 mt per year. It is unknown if this an actual loss to the population and, if a loss, if it was temporary or permanent. Emigration to unsurveyed areas and/or unexplained natural mortality could account for this apparent decline, among other factors.

The Atlantic population of spiny dogfish is more productive than is the northwest Pacific population. However, the long gestation period (~ 2 years), late age of sexual maturation and slow growth rate for spiny dogfish means that the species is relatively unproductive compared to other fish species.

Spring minimum trawlable biomass estimates for spiny dogfish in Canadian and U.S. waters show similar trends, increasing from the early 1980s to the early 1990s, then declining somewhat to the present. Mean values for both indices were around 500,000 mt in the early 1990s, declining to about 300,000 mt in 2007 for the Canadian index. The Canadian spring index is considered to be a better indicator of total adult biomass than is the summer index.

The trends in summer/fall minimum trawlable biomass estimates for spiny dogfish in Canadian and U.S. waters show more variability than do those from the spring. Both indices show a consistent upward or stable trend from about 1985 to the present. The most recent Canadian biomass value is about 350,000 mt (corresponding to about 200 million fish). The summer index is considered to be a better indicator of sub-adult biomass than adult biomass.

It is not currently possible to estimate trends in mature female biomass for spiny dogfish in Atlantic Canada. However, mature female biomass in the U.S. spring RV survey has declined to much lower values in recent years, albeit with an upturn in the last two years. Without knowing the extent that Canadian spawners contribute to the health of northwest Atlantic dogfish metapopulation, it may not be wise to increase the exploitation rate on mature females.

Other Considerations

A spring RV survey of 4X would greatly improve the ability to monitor mature female biomass in Canada, as would a summer survey in shallow inshore waters and the upper Bay of Fundy.

Research to identify the habitat for pupping and the juvenile pelagic stage, and to quantify pup abundance, would aid in predicting stock abundance and determining stock composition.

Further research on stock structure and cross-border movements is required, perhaps through acoustic tagging of both adult and juvenile stages.

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Table 1. Summary statistics for all loci for each sampling location. The sample number used (N), number of alleles (NA), Observed Heterozygosity (Hobs), Expected Heterozygosity (Hexp), FIS (Weir and Cockerham, 1984) (f), Brookfield's (1996) frequency of null alleles r and Hardy Weinberg Probability test results (HWE) are shown for each of the 7 loci and 6 sampling locations.

Locus		Shelburne (SHEL)	Lower Bay of Fundy (LBF)	Freeport (FREE)	Newfoundland (NFLD)	Sambro (SAM)	Upper Bay of Fundy (UBF)
DFH429	N	49	53	41	25	54	42
	N_A	7	7	10	7	7	6
	H_{obs}	0.571	0.642	0.585	0.680	0.611	0.500
	H_{exp}	0.742	0.792	0.777	0.733	0.749	0.773
	f	0.2398	0.1996	0.2578	0.0923	0.1927	0.3636
	r	0.0980	0.0842	0.1077	0.0305	0.0786	0.1540
	HWE	**0.0031**	0.0845	**0.0019**	0.1337	0.3812	**0.0000**
DFU285	N	48	58	44	27	54	42
	N_A	9	10	8	8	11	8
	H_{obs}	0.729	0.724	0.659	0.778	0.870	0.762
	H_{exp}	0.769	0.739	0.723	0.759	0.805	0.665
	f	0.0621	0.0288	0.0993	-0.0065	-0.0723	-0.1340
	r	0.0225	0.0085	0.0369	-0.0109	-0.0364	-0.0582
	HWE	0.9024	0.8009	0.4310	0.9982	0.2981	0.4845
DFJ451	N	49	57	44	27	54	41
	N_A	4	5	6	6	6	4
	H_{obs}	0.510	0.632	0.623	0.593	0.519	0.585
	H_{exp}	0.643	0.604	0.638	0.664	0.624	0.678
	f	0.2167	-0.037	0.1917	0.1261	0.1783	0.1493
	r	0.0810	-0.0173	0.0703	0.0429	0.0650	0.0555
	HWE	**0.0078**	0.8358	**0.0149**	0.3950	0.0860	0.5261
DFH434	N	48	57	44	27	54	42
	N_A	18	15	18	12	18	14
	H_{obs}	0.854	0.860	0.864	0.852	0.944	0.762
	H_{exp}	0.864	0.865	0.857	0.869	0.901	0.864
	f	0.0216	0.0147	0.0040	0.0386	0.0390	0.1297
	r	0.0051	0.0027	-0.0035	0.0092	-0.0229	0.0546
	HWE	0.6888	0.3536	0.2675	0.7765	0.8924	**0.0410**
DFU273	N	45	55	40	26	54	42
	N_A	14	13	11	9	14	13
	H_{obs}	0.933	0.836	0.825	0.846	0.630	0.810
	H_{exp}	0.862	0.867	0.880	0.829	0.877	0.840
	f	-0.071	0.0442	0.0748	-0.0009	0.2906	0.0488
	r	-0.0380	0.0163	0.0291	-0.0093	0.1317	0.0168
	HWE	0.7137	0.4407	**0.0028**	**0.0275**	**0.0000**	0.1941

Table 1. Cont'd

Locus		Shelburne (SHEL)	Lower Bay of Fundy (LBF)	Freeport (FREE)	Newfoundland (NFLD)	Sambro (SAM)	Upper Bay of Fundy (UBF)
DFV296	N	48	58	44	27	52	41
	N_A	11	8	11	7	8	9
	H_{obs}	0.833	0.793	0.773	0.704	0.788	0.805
	H_{exp}	0.779	0.758	0.806	0.726	0.769	0.789
	f	0.0589	-0.0372	0.0531	0.05	-0.0155	-0.0072
	r	-0.0304	-0.0198	0.0186	0.0131	-0.011	-0.0086
	HWE	0.7056	0.0526	0.7914	0.3152	0.1901	0.6153
DFT289	N	48	57	42	27	54	41
	N_A	8	10	6	6	9	7
	H_{obs}	0.396	0.368	0.405	0.444	0.519	0.463
	H_{exp}	0.372	0.342	0.407	0.442	0.455	0.479
	f	-0.0531	-0.0681	0.0176	0.0127	-0.1294	0.0458
	r	-0.0172	-0.0196	0.0016	-0.0019	-0.0434	0.019
	HWE	1	0.6959	0.3426	0.6523	0.8051	0.4844

Table 2. Pairwise Θ (Weir and Cockerham, 1984) estimation of F_{ST} values for each sampling location.

Sampling locations were Shelburne (SHEL), Lower Bay of Fundy (LBF), Freeport (FREE), Newfoundland (NFLD), Sambro (SAM) and Upper Bay of Fundy (UBF)

	SHEL	LBF	FREE	NFLD	SAM	UBF
SHEL						
LBF	-0.00064					
FREE	0.00284	-0.00112				
NFLD	-0.00268	0.00055	0.00119			
SAM	-0.00346	-0.00047	0.00063	-0.00507		
UBF	0.00468	0.00072	0.00171	0.00251	**0.00845**	

Bolded values are significant a $P<0.05$ level

Table 3. Summary of spiny dogfish tagging studies in the NW Atlantic

Study	Tagging location	Tagging Years	Tagging Season	Tagging N	Recap N	Recaps in US		Recaps in Canada		% remaining in tagging country		Dogfish catch (as index of e	
						after 0-1 yr	after 1+ yr	after 0-1 yr	after 1+ yr	no weighting	catch weighting	in US (mt)	in Canada
Myklevoll (1993)	Georges (US)	1968	Aug-Sept	500	14	6	5	1	2	79		158+foreign**	foreign**
Jensen (1969)	Mass (US)	1956-1961	Jun-Jul	155	9	0	9	0	0	100		235+foreign**	foreign**
Jensen (1966)	Maine and Mass (US	1956-1961	Jun-Jul	844	16	7	7	0	2	88		235+foreign**	foreign**
Shafer (1970)	RI, NJ, Maine (US)	1966-1969	Aug-Nov	2934	47	25	16	5	1	87		200+foreign**	39+foreign**
Shafer (1970)	NC (US)	1967	Dec	649	13	7	5	1	0	92		278+foreign**	39+foreign**
Rulifson (unpublished)	NC (US)	1997-2006	Jan-Mar	36604	285	182	77	13	3	94			
Moore (1998)***	Minas Basin (Can)	1996	Jul-Aug	995	39	8	2	9	20	74	95	98765	20099
Jensen (1966,1969)	Browns Bank (Can)	1957	Oct	50	2	0	0	1	1	100			
Templeman (1984)*	St Pierre Bank (Can)	1963, 1965	May-Jun	1936	151	0	3	68	80	98		730	9+foreign**
Templeman (1984)	Inshore NL (Can)	1963-1965	Oct-Dec	442	67	0	0	2	65	100		730	9+foreign**
Templeman (1954)	St John's, NF (Can)	1942	July	279	14	1	2	3	8	79			
Kelly (2005, 2006)***	Bay of Fundy (Can)	2005-2006	Aug	743	10	0	0	9	1	100		2372	4567

Table 4. Comparison of total stratified RV numbers and biomass on the Scotian Shelf (4VWX) between spring and summer 1979-1984.

Spring (March)

Year	Units	Numbers		Weights	
		Stratified Total	Stratified Mean	Stratified Total	Stratified Mean
1979	3799807	25898828	6.82	53265179	14.02
1980	3502110	58256830	16.63	2E+08	57.13
1981	3386862	72237302	21.33	2.67E+08	78.8
1982	3423979	71876833	20.99	1.13E+08	32.99
1983	3954968	3.06E+08	77.42	3.44E+08	87.07
1984	3954968	53361343	13.49	1.36E+08	34.37

Spring/summer	1979	1.89	1.97	2.54	2.64
	1980	1.29	1.46	2.84	3.21
	1981	5.19	6.06	15.89	18.54
	1982	1.17	1.35	1.19	1.37
	1983	3.83	3.83	3.67	3.67
	1984	1.18	1.17	2.15	2.15
	Mean	**2.42**	**2.64**	**4.71**	**5.26**

Summer

Year	Units	Numbers		Weights	
		Stratified Total	Stratified Mean	Stratified Total	Stratified Mean
1979	3954968	13688938	3.46	21009717	5.31
1980	3954968	45164722	11.42	70387914	17.8
1981	3954968	13928643	3.52	16798303	4.25
1982	3954968	61575750	15.57	95224387	24.08
1983	3954968	79997348	20.23	93908146	23.74
1984	3941325	45380190	11.51	63112158	16.01

Table 5. Comparison of total stratified RV numbers and biomass in the 4VW cod (March) vs July RV survey of 4VW.

Spring		Numbers		Weights	
Year	Units	Stratified Total	Stratified Mean	Stratified Total	Stratified Mean
1986	2084048	75530783	36.24	1.32E+08	63.49
1987	2084048	5643380	2.71	20553539	9.86
1988	2084048	1.06E+08	50.97	1.85E+08	88.77
1989	1848297	35565052	19.24	54654712	29.57
1990	2084048	83679068	40.15	1.77E+08	84.94
1991	2084048	1.1E+08	52.66	1.33E+08	63.61
1992	2084048	1.25E+08	59.93	1.56E+08	74.91
1993	2262683	57301	0.03	114601	0.05
1994	2200398	24624284	11.19	47159057	21.43
1995	2425725	551813	0.23	696663	0.29
1996	2230566	7086510	3.18	18092423	8.11
1997	2262683	8893129	3.93	21264799	9.4
1998					
1999	2262683	1742690	0.77	1501740	0.66
2000	2262683	9332036	4.12	76722458	33.91

Summer		Numbers		Weights	
Year	Units	Stratified Total	Stratified Mean	Stratified Total	Stratified Mean
1986	2667322	5886967	2.21	7865355	2.95
1987	2667322	2759743	1.03	2915448	1.09
1988	2667322	5037574	1.89	7321650	2.74
1989	2667322	1763286	0.66	1878138	0.7
1990	2667322	533274	0.2	583665	0.22
1991	2667322	1281078	0.48	955415	0.36
1992	2667322	4793936	1.8	8021111	3.01
1993	2667322	18932873	7.1	28170193	10.56
1994	2667322	926247	0.35	1420409	0.53
1995	2667322	5861712	2.2	8364545	3.14
1996	2667322	1645403	0.62	1168393	0.44
1997	2667322	5431505	2.04	9229843	3.46
1998	2667322	773482	0.29	919763	0.34
1999	2667322	3915015	1.47	1999993	0.75
2000	2667322	1283211	0.48	1492318	0.56

Spring/summer					
	1986	12.8	16.4	16.8	21.5
	1987	2.0	2.6	7.0	9.0
	1988	21.1	27.0	25.3	32.4
	1989	20.2	29.2	29.1	42.2
	1990	156.9	200.8	303.3	386.1
	1991	85.7	109.7	138.7	176.7
	1992	26.1	33.3	19.5	24.9
	1993	0.0	0.0	0.0	0.0
	1994	26.6	32.0	33.2	40.4
	1995	0.1	0.1	0.1	0.1
	1996	4.3	5.1	15.5	18.4
	1997	1.6	1.9	2.3	2.7
	1998				
	1999	0.4	0.5	0.8	0.9
	2000	7.3	8.6	51.4	60.6
	MEAN:	**26.1**	**33.4**	**45.9**	**58.3**

Table 6. Comparison of total stratified abundance in spring and fall RV surveys of southern Newfoundland (3LNO) waters.

Year	Fall	Spring	Spring/Fall
1985		37832	
1986		47366	
1987			
1988	29558	4541	0.15
1989	15388		
1990	108175		
1991			
1992	204935	306037	1.49
1993	78968	41736	0.53
1994	149997	12414	0.08
1995		5517	
1996	209641	497847	2.37
1997	21444	39202	1.83
1998	151785	64524	0.43
1999	51448	127292	2.47
2000	191584	64073	0.33
2001		14925	
2002		20497	
2003	4647		
2004		11555	
2005		48009	
TOTAL	1089360	1157665	1.06

Table 7. Comparison of stratified RV numbers per tow in the US spring vs fall RV surveys. Data from 2006 SARC spiny dogfish assessment.

Year	Spring	Autumn	Spring/fall
1968	24.3	19.7	1.2
1969	13.3	27.7	0.5
1970	15.3	16.6	0.9
1971	15.9	12.9	1.2
1972	27.6	10.5	2.6
1973	35.6	15.0	2.4
1974	39.1	4.7	8.3
1975	35.4	17.7	2.0
1976	23.1	14.9	1.6
1977	13.1	6.8	1.9
1978	22.5	26.0	0.9
1979	10.1	22.0	0.5
1980	29.0	5.1	5.7
1981	41.7	75.7	0.6
1982	51.6	13.7	3.8
1983	41.7	32.4	1.3
1984	22.5	22.5	1.0
1985	117.3	38.7	3.0
1986	28.7	27.4	1.0
1987	65.1	32.8	2.0
1988	64.6	35.3	1.8
1989	56.7	12.8	4.4
1990	91.8	26.1	3.5
1991	62.3	38.4	1.6
1992	79.5	39.1	2.0
1993	60.9	6.9	8.8
1994	91.5	30.9	3.0
1995	50.8	30.6	1.7
1996	97.3	32.8	3.0
1997	58.7	27.9	2.1
1998	43.5	22.0	2.0
1999	56.8	17.9	3.2
2000	37.9	22.8	1.7
2001	31.2	35.0	0.9
2002	50.9	31.2	1.6
2003	49.9	11.7	4.3
2004	28.3	27.9	1.0
2005	48.3	32.4	1.5
MEAN			**2.38**

Table 8. Reported landings (mt) of spiny dogfish by country by year.

Northwest Atlantic (NAFO Areas 2-6)

Year	Canada	US Commercial	US Recreational	US Discards	Germany	Poland	Japan	Spain	Russia	other countries	Total
1960		455			129						584
1961		438			25						463
1962		235		NA	9					8	252
1963		610		NA	13					1	624
1964		730		NA	33					16	779
1965	9	488		NA					188	10	695
1966	39	578		NA					9389		10006
1967		278		NA	98				2436	10	2822
1968		158		NA	15				3950		4123
1969		113		NA	364				8827		9304
1970	19	106		NA	34				4924	686	5769
1971	4	73		NA	730				10792	40	11639
1972	3	69		NA	694				23302		24068
1973	20	89		NA	665	3850	14		14241	56	18935
1974	36	127		NA	118	3848			20444	109	24682
1975	1	147		NA	62	115			22331	15	22671
1976	3	550		NA	12	58			16681	37	17341
1977	1	931		NA	6	70	0	69	6942	112	8131
1978	84	828		NA	0		33	6	577	6	1534
1979	1331	4753		NA			40	36	105	6	6271
1980	660	4085		NA		7	153	83	351	5	5344
1981	564	6865	1493	296			421	37	516	22	10214
1982	389	5411	70	349	5	103	175	58	27	32	6619
1983		4897	67	540	51	29	60		359	291	6294
1984	2	4450	91	424	2	31	67		291	95	5453
1985	13	4028	89	964	6	162	150		694	720	6826
1986	20	2748	182	1187		19	135		214	383	4888
1987	281	2703	306	1056		7	56		140	267	4817
1988	1	3105	359	876		68	19		1192	21	5641
1989	167	4492	418	1344		47	45		2186	590	9289
1990	1309	14731	179	1170		0	16		1294	807	19506
1991	307	13177	131	1350			18		729	695	16406
1992	868	16858	215	1019			2		510	162	19633
1993	1435	20643	120	1110					74	310	23692
1994	1820	18800	154	969			28			17	21787
1995	956	22711	64	628			17			31	24407
1996	431	27241	34	353			38	199	0	112	28408
1997	446	18352	64	749			3	211		96	19921
1998	1055	20628	39	610			2	605	0	9	22948
1999	2091	14860	53	532				554		49	18138
2000	2741	9257	5	604				402	16		13024
2001	3820	2294	28	2090				677	0		8909
2002	3584	2199	225	1698				474	3		8183
2003	1302	1170	40	2987				643	9	1	6152
2004	2362	981	109	3368				324	13	43	7200
2005	2267	1150	36	3083				168	2	8	6714
2006	2300										2300

Notes:
Canada for 1960 - 85 is from NAFO
Canada for 1986 - 02 is from DFO ZIF
Canada for 2003 - 07 is from DFO MARFIS
Northwest Atlantic Data (US/ 1962-2005) is from US 2006 spiny dogfish assessment
Northwest Atlantic Data (US/ 1960-1961) is from NAFO
Germany for 1960 - 05 is from NAFO
Poland for 1960 - 05 is from NAFO
Japan for 1960 - 05 is from NAFO
Spain for 1960 - 05 is from NAFO
USSR for 1960 - 05 is from NAFO
Other countries for 1960 - 80, 04, 05 is from NAFO
Other countries for 1981 - 03 is from IOP non-Canadian kept catch

Table 9. Canadian landings (mt) of spiny dogfish by fishery by year.

Year	Directed handline/ longline	Undirected groundfish handline/longline	Groundfish OTB<65'	Groundfish OTB>65'	Silver hake	Gillnet	OTB redfish	Danish/ Scottish Seine	Other fishery	Total dogfish	TAC
1986		13		2		6				20	NA
1987	11	238	25			7	1			281	NA
1988		0	0	0		0	0		0	1	NA
1989	123	0	37	0		7	0		0	167	NA
1990	663	74	164	61		338	0	8	0	1309	NA
1991	271	9	1	10	10	0	0	6	0	307	NA
1992	676	21	2	2	36	130		1	0	868	NA
1993	674	19	15	2	23	700	0	2		1435	NA
1994	857	20	10	0	0	906	17	8	1	1820	NA
1995	342	13	11	3	0	586	0	1		956	NA
1996	52	8	30	1	5	332	1	2	0	431	NA
1997	207	14	51	0		171	1	2		446	NA
1998	819	12	44	0		170	1	1	6	1055	NA
1999	1856	26	6		3	194	1	3	1	2091	NA
2000	2468	24	43		3	202	1			2741	NA
2001	3063	37	21	0	1	696	1	0		3820	NA
2002	2870	36	6		5	662	0	4		3584	3200
2003	851	27	0		3	418	3			1302	3200
2004	1986	31	1		2	343	0			2362	2500
2005	1936	33	3		2	296				2270	2500
2006	1743	42			1	513	0			2300	2500

Table 10. Canadian spiny dogfish landings (mt) by province.

Year	NS	NB	PE	QC	NF	Total
1986	10		1	10	0	20
1987	234	36		11		281
1988	1			0	0	1
1989	165	2	0	0	0	167
1990	915	34	284	74	1	1309
1991	163	0	1	141	2	307
1992	748	0	2	117	0	868
1993	728	225	317	165		1435
1994	845	5	833	129	7	1820
1995	390	1	418	141	6	956
1996	97	5	136	188	5	431
1997	391	0	23	32		446
1998	924	59	47	20	5	1055
1999	1874	17	9	191	0	2091
2000	2525	97	5	114	0	2741
2001	3367	219	6	115	114	3820
2002	3270	173	0	19	122	3584
2003	1302					1302
2004	2091	271				2362
2005	2202	66				2267
2006	2300					2300

Table 11. Observer coverage (%) of the fisheries shown in Table 4 in which spiny dogfish were caught as a bycatch, broken down by NAFO division and year

NAFO grouping		1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Nafo 2,3	Total observed target catch in fisheries (mt)	11242	31085	30553	25690	12854	8763	6757	11414	2693	452	2783	699	1242	1510	1626	750	578	937	244	114	76
	Total ZIF/MARFIS target catch in fisheries	280550	377051	389668	332046	320458	242854	118251	68330	25807	11864	19184	29907	45466	48895	58509	58270	40331	2407	2311	2873	2229
	% Observer coverage	**4**	**8**	**8**	**8**	**4**	**4**	**6**	**17**	**10**	**4**	**15**	**2**	**3**	**3**	**3**	**1**	**1**	**39**	**11**	**4**	**3**
	Total observed dogfish (mt)	38	0	0	2	8	0	1	1	0	0	2	2	1	3	2	0	1	1	0	0	0
Nafo 4RST	Total observed target catch in fisheries (mt)	1967	619	857	872	5382	3595	1734	1626	922	1	7	3	120	354	147	157	236	2	73	17	42
	Total ZIF/MARFIS target catch in fisheries	155209	153430	136708	131683	104898	99398	99556	66228	49381	43091	39457	52911	39246	26691	37505	75638	39198	3695	681	586	548
	% Observer coverage	**1**	**0**	**1**	**1**	**5**	**4**	**2**	**2**	**2**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**11**	**3**	**0**
	Total observed dogfish (mt)	0	0	0	0	0	0	1	1	4	0	0	0	2	0	2	0	0	0	0	0	0
Nafo 4Vn	Total observed target catch in fisheries (mt)	320	2505	2712	3433	2408	6388	4779	4965	1808	1049	98	99	79	332	195	213	181	32	161	6	119
	Total ZIF/MARFIS target catch in fisheries	31337	30039	28277	27446	21251	19997	21878	13586	4475	11264	2237	3521	3230	7264	2124	2931	2999	1853	1456	1196	1161
	% Observer coverage	**1**	**8**	**10**	**13**	**11**	**32**	**22**	**37**	**40**	**9**	**4**	**3**	**2**	**5**	**9**	**7**	**6**	**2**	**11**	**0**	**10**
	Total observed dogfish (mt)	0	0	0	3	1	1	3	4	2	0	0	0	0	3	1	0	0	0	0	0	0
Nafo 4Vs	Total observed target catch in fisheries (mt)	7250	5064	5913	5438	11206	6118	3508	1628	2653	2539	1321	1535	277	636	205	679	11	107	5	109	1
	Total ZIF/MARFIS target catch in fisheries	68868	59079	49117	46425	42124	32343	28783	7027	7379	6913	2988	3510	1783	3565	2312	4679	2928	2097	1934	2319	2855
	% Observer coverage	**11**	**9**	**12**	**12**	**27**	**19**	**12**	**23**	**36**	**37**	**44**	**44**	**16**	**18**	**9**	**15**	**0**	**5**	**0**	**5**	**0**
	Total observed dogfish (mt)	7	1	8	6	20	1	2	1	5	4	49	21	0	0	1	0	0	0	0	0	0
Nafo 4W	Total observed target catch in fisheries (mt)	843	930	773	1105	1615	17806	13768	27560	6228	17042	24996	11557	7195	5119	2235	2867	3594	399	538	442	504
	Total ZIF/MARFIS target catch in fisheries	18472	10475	8482	16331	15220	58255	34845	19124	8337	16092	36661	37181	28492	13144	22415	16734	38304	11817	17214	15243	17751
	% Observer coverage	**5**	**9**	**9**	**7**	**11**	**31**	**40**	**144**	**75**	**106**	**68**	**31**	**25**	**39**	**10**	**17**	**9**	**3**	**3**	**3**	**3**
	Total observed dogfish (mt)	32	3	24	66	70	817	139	263	22	29	184	79	13	52	0	0	7	0	1	0	0
Nafo 4X5Y	Total observed target catch in fisheries (mt)	476	1031	2692	3030	3812	4693	5182	15588	1730	8062	4335	3451	1431	3384	9306	5094	5355	3949	3721	883	854
	Total ZIF/MARFIS target catch in fisheries	82531	120585	143919	148982	152786	144231	165519	101179	103437	124646	84226	97331	106516	87413	113664	148689	65525	113835	97542	67491	65204
	% Observer coverage	**1**	**1**	**2**	**2**	**2**	**3**	**3**	**15**	**2**	**6**	**5**	**4**	**1**	**4**	**8**	**3**	**8**	**3**	**4**	**1**	**1**
	Total observed dogfish (mt)	9	58	37	70	139	219	117	230	83	48	50	105	9	79	87	57	109	46	101	78	27
Nafo 5Z	Total observed target catch in fisheries (mt)	69	887	314	843	1218	853	789	2257	1613	265	1540	776	1266	1171	1497	1545	1092	1177	1753	3136	4410
	Total ZIF/MARFIS target catch in fisheries	13967	18853	21683	12576	19464	20663	19199	17296	13617	4731	9900	7916	8392	8654	11531	13558	12153	12044	13246	17097	14113
	% Observer coverage	**0**	**5**	**1**	**7**	**6**	**4**	**4**	**13**	**12**	**6**	**16**	**10**	**15**	**14**	**13**	**11**	**9**	**10**	**13**	**18**	**31**
	Total observed dogfish (mt)	13	14	0	1	4	11	18	29	3	0	3	26	0	3	0	0	2	0	1	1	55

Table 12. Canadian landings, discards and discard mortality (mt) of spiny dogfish by NAFO division and fishery by year

Year	Subarea	Total Landings (mt)	Discards: Directed dogfish	Groundfish LL	Groundfish OTB<65'	Groundfish OTB>65'	Silver hake	Gillnet	OTB redfish	Herring	Danish seine	Total discards	Discard mortality*	Landings Annual total	Discard mortality Annual total
1986	2-3	0	0	0	0	297	0	0	0	0	0	297	63	20	551
	4RST	11	0	0	0	0	0	0	0	0	0	0	0		
	4Vn	1	0	0	0	10	0	0	10	0	0	20	5		
	4Vs		0	0	0	44	0	0	1	0	0	45	10		
	4W	1	0	0	30	87	0	0	31	0	0	148	32		
	4X/5Y	8	0	220	1146	504	0	0	265	0	0	2135	436		
	5Z		0	3	0	27	0	0	0	0	0	30	6		
1987	2-3		0	0	1	0	0	0	0	0	0	1	0	281	1502
	4RST	12	0	0	0	0	0	0	0	0	0	0	0		
	4Vn		0	0	0	4	0	0	0	0	0	4	1		
	4Vs		0	0	0	11	0	0	1	0	0	12	3		
	4W	5	0	0	9	8	0	0	14	0	0	31	7		
	4X/5Y	264	0	170	6141	364	0	0	17	0	0	6692	1403		
	5Z		0	5	65	349	0	0	0	0	0	419	88		
1988	2-3	0	0	0	0	11	0	0	0	0	0	11	2	1	1131
	4RST	0	0	0	0	0	0	0	23	0	0	23	5		
	4Vn	0	0	0	0	1	0	0	0	0	0	1	0		
	4Vs		0	0	0	120	0	0	0	0	0	120	26		
	4W	0	0	0	6	27	0	0	2553	0	0	2586	613		
	4X/5Y	0	0	192	1741	136	0	0	208	0	0	2277	467		
	5Z	0	0	6	75	0	0	0	0	0	0	81	17		
1989	2-3	0	0	17	0	9	0	0	40	0	0	66	13	167	647
	4RST	5	0	0	0	0	0	0	9	0	0	9	2		
	4Vn	0	0	0	0	4	0	0	36	0	0	40	9		
	4Vs	0	0	0	0	28	0	0	1	0	0	29	6		
	4W	0	0	0	5	78	45	0	43	0	0	171	39		
	4X/5Y	162	0	370	1362	151	0	0	869	0	0	2752	565		
	5Z		0	51	34	0	0	0	0	0	0	85	12		
1990	2-3	2	0	80	0	61	0	0	10	0	0	151	23	1309	349
	4RST	616	0	0	18	0	0	0	1	0	0	19	4		
	4Vn	41	0	0	0	1	0	0	2	0	0	3	1		
	4Vs		0	5	0	61	0	0	5	0	0	71	15		
	4W	29	0	0	7	245	0	0	3	0	0	255	54		
	4X/5Y	620	0	396	641	179	0	0	93	0	0	1309	236		
	5Z	1	0	141	5	5	0	0	0	0	0	151	16		
1991	2-3	3	0	38	0	0	0	0	0	0	0	38	4	307	587
	4RST	146	0	0	16	0	0	0	0	0	0	16	3		
	4Vn		0	0	1	0	0	0	4	0	0	5	1		
	4Vs	0	0	1	0	3	0	0	0	0	0	4	1		
	4W	15	0	67	106	479	102	0	97	0	0	851	180		
	4X/5Y	143	0	1155	626	548	0	0	54	0	0	2383	378		
	5Z		0	137	8	23	0	0	0	0	0	168	20		
1992	2-3	0	0	4	0	9	0	0	3	0	0	16	3	868	2296
	4RST	310	0	0	16	0	0	0	2	0	0	18	4		
	4Vn		0	0	2	1	0	0	8	0	0	11	3		
	4Vs	0	0	1	0	7	0	0	2	0	0	10	2		
	4W	40	0	3247	40	86	161	3	32	0	0	3569	401		
	4X/5Y	517	0	1662	1554	648	12	2143	136	0	0	6155	1848		
	5Z		0	123	49	59	0	1	0	0	0	232	36		
1993	2-3	0	0	6	1	4	0	0	2	0	0	13	2	1435	1030
	4RST	706	0	0	2	0	0	0	33	0	0	35	8		
	4Vn	0	0	1	0	0	0	0	4	0	0	5	1		
	4Vs	32	0	77	0	1	0	0	2	0	0	80	8		
	4W	696	0	63	5	88	18	0	0	0	0	174	31		
	4X/5Y	0	0	1150	613	229	2	1148	68	10	0	3220	944		
	5Z		0	81	7	65	0	22	0	0	0	175	36		
1994	2-3	7	0	2	0	0	0	0	1	0	0	3	0	1820	586
	4RST	978	0	0	0	0	0	0	17	0	0	17	4		
	4Vn	15	0	3	0	0	0	0	3	0	0	6	1		
	4Vs	4	0	1	0	0	0	0	7	0	0	8	2		
	4W	11	0	11	0	11	0	0	6	0	0	28	5		
	4X/5Y	806	0	146	290	50	0	451	520	403	0	1860	559		
	5Z		0	0	29	2	0	15	0	0	0	46	15		
1995	2-3	6	0	1	0	0	0	0	1	0	0	2	0	956	847
	4RST	560	0	4	0	0	0	0	0	0	0	4	0		
	4Vn	1	0	0	0	0	0	0	11	0	0	11	3		
	4Vs	6	0	2	0	4	0	0	5	0	0	11	2		
	4W	10	0	12	2	3	11	0	2	0	0	30	5		
	4X/5Y	373	0	138	911	76	1	877	394	127	0	2524	831		
	5Z		0	1	0	0	0	8	0	0	0	9	5		
1996	2-3	5	0	4	0	0	0	0	1	0	0	5	1	431	718
	4RST	365	0	2	0	0	0	0	0	0	0	2	0		
	4Vn	0	0	2	0	0	0	0	1	0	0	3	0		
	4Vs	0	0	7	0	1	0	0	51	0	0	59	13		
	4W	5	0	11	0	14	8	0	70	0	0	103	23		
	4X/5Y	55	0	835	707	84	0	656	226	53	0	2561	679		
	5Z		0	0	2	1	0	2	0	0	0	5	2		
1997	2-3		2	24	0	0	0	0	0	0	0	24	2	446	888
	4RST	187	0	16	1	0	0	0	0	0	0	17	2		
	4Vn	0	0	1	0	0	0	0	1	0	0	2	0		
	4Vs	6	0	5	0	0	0	0	35	0	0	40	9		
	4W	32	0	14	3	3	273	0	59	0	0	352	85		
	4X/5Y	241	0	574	378	18	13	805	606	0	0	2394	731		
	5Z	0	0	44	136	6	0	42	1	0	0	229	58		
1998	2-3	5	0	7	0	0	0	0	1	0	0	8	1	1055	663
	4RST	180	0	14	0	0	0	0	5	0	0	19	3		
	4Vn	1	0	6	0	0	0	0	7	0	0	13	2		
	4Vs	1	0	3	0	0	0	0	1	0	0	4	1		
	4W	22	0	4	3	15	34	0	1	0	0	57	13		
	4X/5Y	846	0	413	421	217	5	807	91	0	0	1954	644		
	5Z	0	0	0	0	0	0	0	0	0	0	0	0		
1999	2-3	0	0	13	0	0	0	0	0	0	0	13	1	2091	769
	4RST	200	0	9	4	0	0	0	1	0	0	14	2		
	4Vn	0	0	4	0	0	0	0	60	0	0	64	15		
	4Vs	2	0	3	0	1	0	0	0	0	0	4	1		

	4W	89	0	5	4	67	31	0	7	0	0	114	25			
	4X/5Y	1798	0	373	1122	46	30	506	484	131	0	2692	719			
	5Z	0	0	8	15	0	0	4	1	0	0	28	6			
2000	2-3	0	0	3	0	0	0	0	0	0	0	3	0		2741	1015
	4RST	163	0	29	0	0	0	0	9	0	0	38	5			
	4Vn	0	0	4	0	0	0	0	7	0	0	11	2			
	4Vs	0	0	0	0	6	0	0	2	0	0	8	2			
	4W	32	0	5	1	1	1	0	0	0	0	8	1			
	4X/5Y	2545	0	109	386	51	0	445	2531	207	0	3729	1001			
	5Z	1	0	0	0	0	0	6	0	0	0	6	3			
2001	2-3	114	0	2	0	0	0	0	37	0	0	39	9		3820	636
	4RST	169	0	36	0	0	0	0	3	0	0	39	4			
	4Vn	0	0	2	0	0	0	0	0	0	0	2	0			
	4Vs	0	0	0	0	0	0	0	0	0	0	0	0			
	4W	105	0	1	1	2	4	0	7	1	0	16	4			
	4X/5Y	3432	0	328	653	5	23	525	496	122	0	2152	615			
	5Z		0	6	1	0	0	5	0	0	0	12	4			
2002	2-3	122	0	8	0	0	0	0	1	0	0	9	1		3564	682
	4RST	27	0	55	0	0	0	0	0	0	0	55	6			
	4Vn	0	0	4	0	0	0	0	5	0	0	9	2			
	4Vs	0	0	2	0	1	0	0	10	0	0	13	3			
	4W	232	0	30	2	1	7	0	19	0	0	59	10			
	4X/5Y	3202	0	404	266	9	2	809	430	34	0	1954	655			
	5Z		0	3	21	7	0	0	0	0	0	31	6			
2003	2-3		0	3	0	0	0	0	4	0	0	7	1		1302	795
	4RST	9	0	1	0	0	0	0	1	0	0	2	0			
	4Vn		0	2	0	0	0	0	6	0	0	8	2			
	4Vs	0	0	0	0	0	0	0	4	0	0	4	1			
	4W	131	0	2	1	1	5	0	5	0	0	14	3			
	4X/5Y	1161	0	412	235	41	0	975	140	466	0	2269	786			
	5Z		0	0	0	6	0	2	0	0	0	8	2			
2004	2-3	0	0	0	0	0	0	0	4	0	0	4	1		2362	766
	4RST	0	0	1	0	0	0	0	1	0	0	2	0			
	4Vn		0	4	0	0	0	0	0	0	0	4	0			
	4Vs	0	0	1	0	0	0	0	7	0	0	8	2			
	4W	28	0	5	2	0	22	0	6	0	0	35	8			
	4X/5Y	2333	0	126	1956	15	14	475	175	61	0	2822	753			
	5Z		0	6	2	0	0	2	0	0	0	10	2			
2005	2-3		0	0	0	0	0	0	5	0	0	5	1		2267	875
	4RST	2	0	1	0	0	0	0	1	0	0	2	0			
	4Vn	7	0	3	0	0	0	0	3	0	0	6	1			
	4Vs	17	0	1	0	0	0	0	8	0	0	9	2			
	4W	19	0	1	1	1	2	0	0	0	0	5	1			
	4X/5Y	2222	0	672	950	26	1	576	1081	70	0	3376	866			
	5Z		0	18	1	0	0	3	1	0	0	23	4			
2006	2-3		0	1	0	0	0	0	4	0	0	5	1		2300	504
	4RST		0	1	0	0	0	0	0	0	0	1	0			
	4Vn		0	3	0	0	0	0	3	0	0	6	1			
	4Vs	18	0	0	0	0	0	0	12	0	0	12	3			
	4W	140	0	4	1	2	1	0	3	0	0	11	2			
	4X/5Y	2142	0	235	955	17	0	364	215	0	0	1786	481			
	5Z		0	25	59	1	0	0	1	0	0	86	15			

* discard mortality based on 25% for OTB catches > 200 kg, 55% for gillnet catches, 10% for longline, 25% for purse seine

Table 13. Total stratified abundance and biomass (kg) of spiny dogfish in the July RV survey of NAFO 4VWX5Z.

		Numbers		Weights	
Year	Units	Stratified Total	Stratified Mean	Stratified Total	Stratified Mean
1970	4239783	27614519	6.51	37250223	8.79
1971	4509685	81551163	18.08	1.21E+08	26.87
1972	4239783	12573273	2.97	22293222	5.26
1973	4239783	18552229	4.38	30940707	7.3
1974	4239783	27841909	6.57	44098990	10.4
1975	4239783	3515504	0.83	6152525	1.45
1976	4239783	4161046	0.98	7508930	1.77
1977	4239783	45096122	10.64	74618410	17.6
1978	4239783	810341	0.19	2136818	0.5
1979	4239783	13688938	3.23	21009717	4.96
1980	4239783	45164722	10.65	70387914	16.6
1981	4239783	13955511	3.29	16852039	3.97
1982	4239783	61575750	14.52	95224387	22.46
1983	4239783	80024216	18.87	93961882	22.16
1984	4226140	45555104	10.78	63412554	15
1985	4239783	1.57E+08	37.07	1.97E+08	46.46
1986	4239783	97723295	23.05	1.26E+08	29.7
1987	4239783	1.9E+08	44.87	2.72E+08	64.1
1988	4239783	1.57E+08	37.14	2.28E+08	53.89
1989	4413248	44957234	10.19	67944322	15.4
1990	4413248	59288435	13.43	75484235	17.1
1991	4239783	1.02E+08	24.09	1.33E+08	31.39
1992	4239783	1.08E+08	25.41	1.58E+08	37.27
1993	4239783	1.31E+08	30.93	1.85E+08	43.58
1994	4239783	1.39E+08	32.88	1.78E+08	41.9
1995	4349524	89921128	20.67	1.14E+08	26.22
1996	4349524	2.42E+08	55.62	3.37E+08	77.43
1997	4349524	2.11E+08	48.53	2.8E+08	64.35
1998	4349524	34579574	7.95	50113611	11.52
1999	4349524	1.69E+08	38.84	2.24E+08	51.44
2000	4349524	1.49E+08	34.33	2.15E+08	49.45
2001	4349524	1.21E+08	27.91	1.85E+08	42.59
2002	4349524	2.95E+08	67.81	4.19E+08	96.24
2003	4349524	33729876	7.75	43168994	9.92
2005	4349524	1.64E+08	37.64	2.35E+08	54.05
2006	4349524	52114812	11.98	87377898	20.09
2007	4323169	2.06E+08	47.68	3.45E+08	79.91

Table 14. Total stratified abundance and biomass (kg) of spiny dogfish in the spring and fall RV surveys of NAFO 4VWX.

Spring		Numbers		Weights	
Year	Units	Stratified Total	Stratified Mean	Stratified Total	Stratified Mean
1979	3799807	25898828	6.82	53265179	14.02
1980	3502110	58256830	16.63	2E08	57.13
1981	3671677	72237302	19.67	2.67E08	72.68
1982	3423979	71876833	20.99	1.13E08	32.99
1983	3954968	3.06E08	77.42	3.44E08	87.07
1984	3954968	53361343	13.49	1.36E08	34.37

Fall		Numbers		Weights	
Year	Units	Stratified Total	Stratified Mean	Stratified Total	Stratified Mean
1978	2220905	851003	0.38	3670129	1.65
1979	4058860	11092201	2.73	24358845	6
1980	4239783	6534286	1.54	13777011	3.25
1981	4118010	3747456	0.91	6645955	1.61
1982	4239783	13178950	3.11	20372267	4.81
1983	4239783	15964208	3.77	22031916	5.2
1984	4239783	58325243	13.76	99183756	23.39

Table 15. Total stratified abundance and biomass (kg) of spiny dogfish in the March RV survey of NAFO 4VW.

		Numbers		Weights	
Year	**Units**	**Stratified Total**	**Stratified Mean**	**Stratified Total**	**Stratified Mean**
1986	2084048	75530783	36.24	1.32E08	63.49
1987	2084048	5643380	2.71	20553539	9.86
1988	2084048	1.06E08	50.97	1.85E08	88.77
1989	1848297	35565052	19.24	54654712	29.57
1990	2084048	83679068	40.15	1.77E08	84.94
1991	2084048	1.1E08	52.66	1.33E08	63.61
1992	2084048	1.25E08	59.93	1.56E08	74.91
1993	2262683	57301	0.03	114601	0.05
1994	2200398	24624284	11.19	47159057	21.43
1995	2425725	551813	0.23	696663	0.29
1996	2230566	7086510	3.18	18092423	8.11
1997	2262683	8893129	3.93	21264799	9.4
1998					
1999	2262683	1742690	0.77	1501740	0.66
2000	2262683	9332036	4.12	76722458	33.91
2001	2262683	104323	0.05	134516	0.06
2002	2262683	1014443	0.45	1255184	0.55
2003	2123453	213610	0.1	181627	0.09
2004					
2005	2084048	91545	0.04	66498	0.03
2006	2146333	764323	0.36	1555976	0.72
2007	2262683	137447	0.06	183267	0.08

Table 16. Total stratified abundance and biomass (kg) of spiny dogfish in the February RV survey of Georges Bank.

		Numbers		Weights	
Year	Units	Stratified Total	Stratified Mean	Stratified Total	Stratified Mean
1986	1600850	3.03E+08	189.07	2.61E+08	162.93
1987	1566276	2.86E+08	182.36	1.8E+08	114.61
1988	1407386	91596451	65.08	57571792	40.91
1989	1407386	2.13E+08	151.62	1.92E+08	136.39
1990	1407386	1.91E+08	135.65	1.19E+08	84.55
1991	1407386	93560875	66.48	1.37E+08	97.35
1992	1407386	6.75E+08	479.93	4.38E+08	311.02
1993	799535	2.39E+08	299.07	2.75E+08	343.51
1994	799535	1.29E+08	161.67	1.28E+08	159.84
1995	1407386	1.56E+08	110.95	1.03E+08	73.11
1996	1407386	34062624	24.2	19600357	13.93
1997	1407386	21752388	15.46	38319165	27.23
1998	1407386	3371611	2.4	5967538	4.24
1999	1407386	5623665	4	6361972	4.52
2000	1407386	9498455	6.75	13534189	9.62
2001	1407386	12335996	8.77	6205226	4.41
2002	1407386	8446923	6	12131147	8.62
2003	1407386	9835141	6.99	14906135	10.59
2004	1407386	1313893	0.93	2242957	1.59
2005	628866	227339	0.36	471061	0.75
2006	1209430	371011	0.31	191739	0.16
2007	1236717	730911	0.59	1832544	1.48

Table 17. Abundance and biomass indices for spiny dogfish observed in various industry surveys for other species on the Scotian Shelf. MG = mobile gear; LL = longline

Year	4VsW Sentinel LL		4X ITQ MG		4Vn Sentinel LL		Halibut LL Survey	
	Number	Weight	Number	Weight	Number	Weight	Number	Weight
1994					347.9	659.4		
1995	20.1	41.4			153.8	205.9		
1996	1.2	1.6	90.9	131.1				
1997	3.0	7.7	131.5	123.5				
1998	0.7	0.9	28.3	26.8	11.2	13.0	20.5	39.4
1999	4.8	6.8	119.4	167.8	42.6	52.0	45.6	79.3
2000	1.6	1.8	261.3	327.8	2.4	4.1	5.3	30.4
2001	1.0	1.8	65.4	82.1	1.0	2.0	21.3	54.7
2002	0.9	1.0	113.4	211.4	0.0	0.0	68.3	147.2
2003	1.5	1.1	16.1	33.1	0.0	0.0	65.6	143.3
2004	0.2	0.3	51.5	91.8	0.0	0.0	17.5	41.9
2005	0.7	1.4	24.3	36.9	0.0	0.0	31.6	105.9
2006			31.2	46.2	0.0	0.0	22.6	86.7

Table 18. Total stratified abundance and biomass (kg) of spiny dogfish in the September RV survey of the southern Gulf of St. Lawrence.

Year	Abundance	Biomass
1971	0	0
1972	0	0
1973	0	0
1974	0	0
1975	0	0
1976	0	0
1977	0	0
1978	0	0
1979	0	0
1980	0	0
1981	0	0
1982	0	0
1983	0	0
1984	7074	44504
1985	543021	853467
1986	519397	997200
1987	269420	611541
1988	23610282	39583787
1989	13171580	19762663
1990	1025847	1997083
1991	3563754	6487270
1992	4639876	8913549
1993	27561968	49592394
1994	6851338	11856369
1995	12594056	24546460
1996	2516200	5237950
1997	8454266	14286211
1998	558533	1088177
1999	8566659	15281947
2000	2200513	4290637
2001	248462	457906
2002	6073215	16853921
2003	0	0
2004	0	0
2005	0	0
2006	128358	218678

Table 19. Total stratified abundance and biomass (kg) of spiny dogfish in the spring RV survey of southern Newfoundland (NAFO 3LNOP).

Year	Abundance	Biomass
1972	1418075	3789479
1973	53596	162038
1974	501269	1505128
1975	2979553	6847758
1976	2032403	3810322
1977	690812	1746118
1978	81327	202640
1979	2989920	8033809
1980	68984	277695
1981	470653	1653477
1982	1797175	4450575
1983	994591	2078033
1984	119878	304006
1985	7634348	15297787
1986	3025694	7393977
1987	98940	227025
1988	2823487	5669865
1989	162930	378655
1990	173148	326854
1991	200346	405389
1992	399251	704913
1993	250827	463810
1994	193914	315946
1995	615155	1074856
1996	1155809	1979307
1997	4488342	7043980
1998	676132	1102309
1999	5480851	8588532
2000	3802243	5832655
2001	4715734	2127219
2002	1544873	2486557
2003	1572996	2316041
2004	13453407	20287937
2005	1065289	1753591

Table 20. Total stratified abundance of mature female spiny dogfish in RV surveys where length frequency. data was available.

Year	Summer RV	Spring RV	Fall RV	4VW cod RV	Georges RV
1970	1335030				
1971	2382480				
1972	1286640				
1973	1153061				
1974	330868				
1975	17321				
1976	66767				
1977	199621				
1978	214535		418217		
1979	165750	5851266	3673362		
1980	260735	34043110	290358		
1981	411626	59048225	470263		
1982	1531910	8295902	576959		
1983	492609	16088363	702875		
1984	799317	25296926	5379358		
1985	3164983				
1986	1979706			13954455	3917906
1987	3395344			4501633	1469095
1988	2563490			20828836	1497684
1989	918990			4660046	1830121
1990	899674			37253825	1466127
1991	790129			3975754	966981
1992	2380501				1126223
1993	983246			0	3960691
1994	1387141			1183436	423552
1995	831161			0	488566
1996	540561			1739879	56211
1997	1771269			4694913	3624887
1998	474433				633606
1999	392073			77257	118094
2000	1388894			211720	739492
2001	2010066			24055	73409
2002	7117520			90020	584712
2003	830786			4615	597717
2004	1630939				179033
2005	2947014			8029	87423
2006	2638972			254774	0
2007	2218637			3565	253047

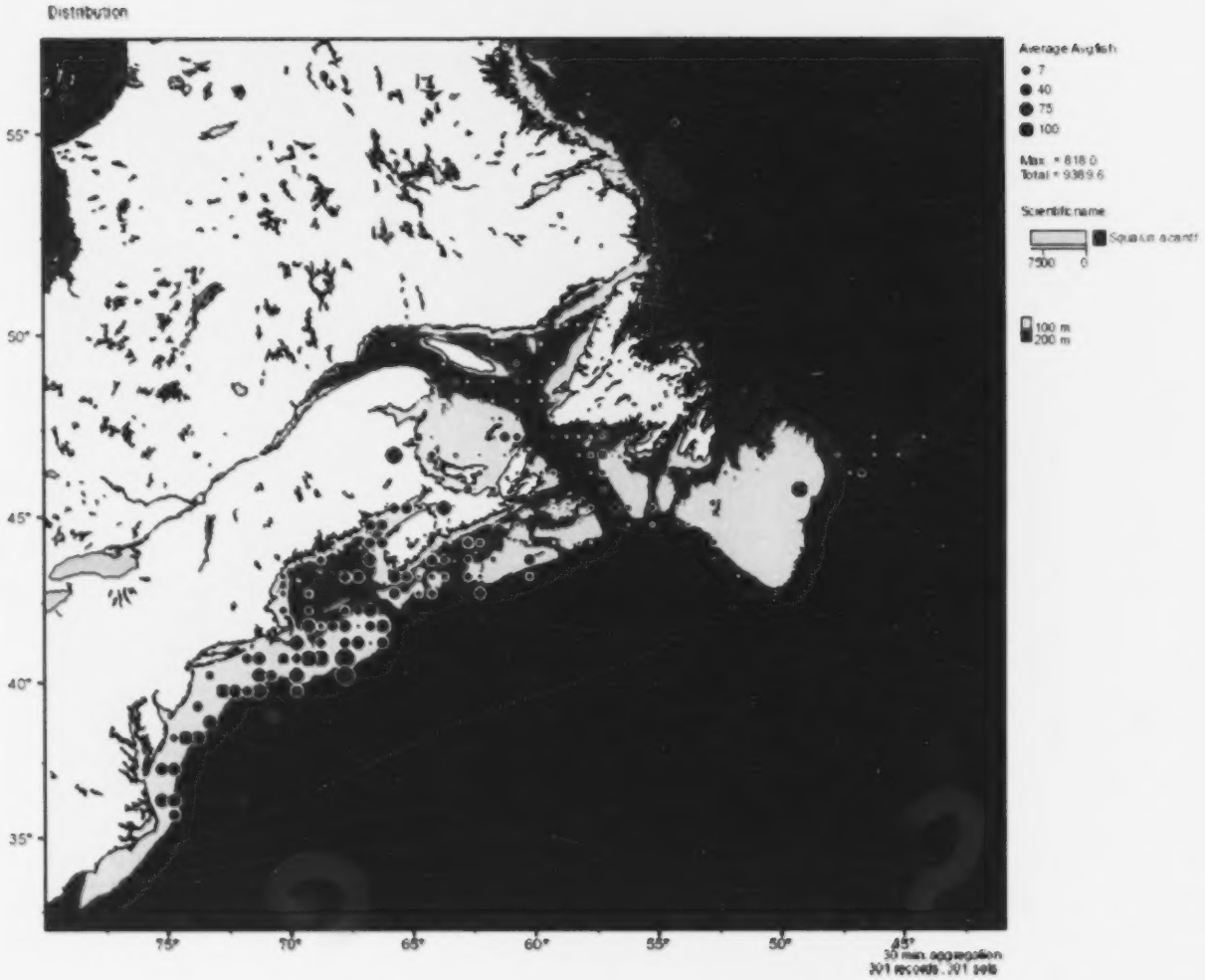


Fig. 1. Distribution of spiny dogfish along the eastern coast of North America as recorded in ECNSAP.

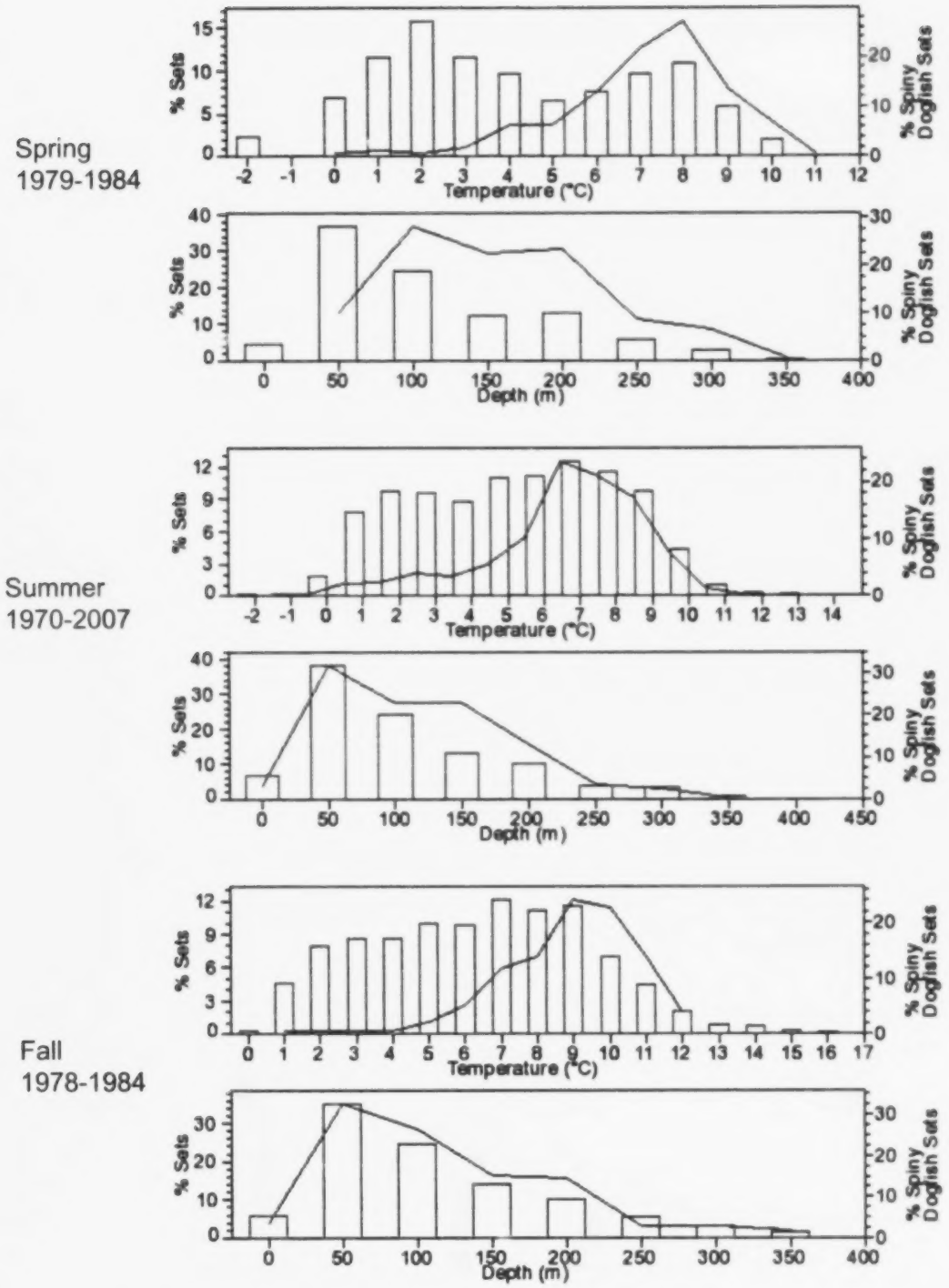


Fig 2. Temperature and depth distribution of spiny dogfish from spring, summer and fall RV surveys of the Scotian Shelf. Percentage of all sets in a given depth or temperature interval is shown as bars, while the percentage of sets containing dogfish in a given depth or temperature interval is shown as a line.

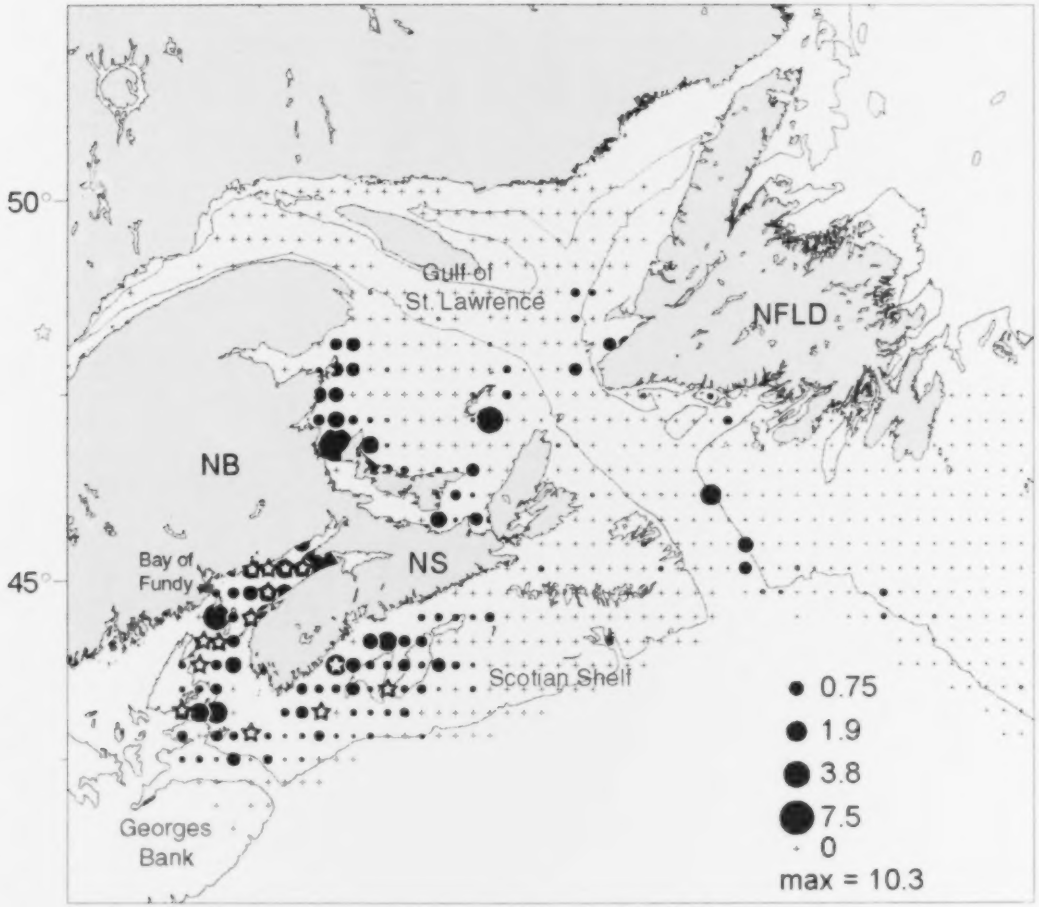


Fig. 3. Distribution of female spiny dogfish of mature size (FL > 73 cm) in summer research surveys of the Scotian Shelf and Gulf of St. Lawrence. Symbols are proportional in size to the mean number of mature dogfish collected within each 20-minute square between 1979 – 2005 inclusive. Survey coverage of the northern Gulf of St. Lawrence and around Newfoundland was 1993 – 2005 (August) and 1971 – 2004 (all months) , respectively. Crosses represent survey sets where mature females were absent. Starred symbols show capture locations of pregnant females in 2003 – 2005 surveys of the Scotian Shelf; maturity examinations were not made in the Gulf or around Newfoundland. The 200-m depth contour is shown. NFLD = Newfoundland; NS = Nova Scotia; NB = New Brunswick.

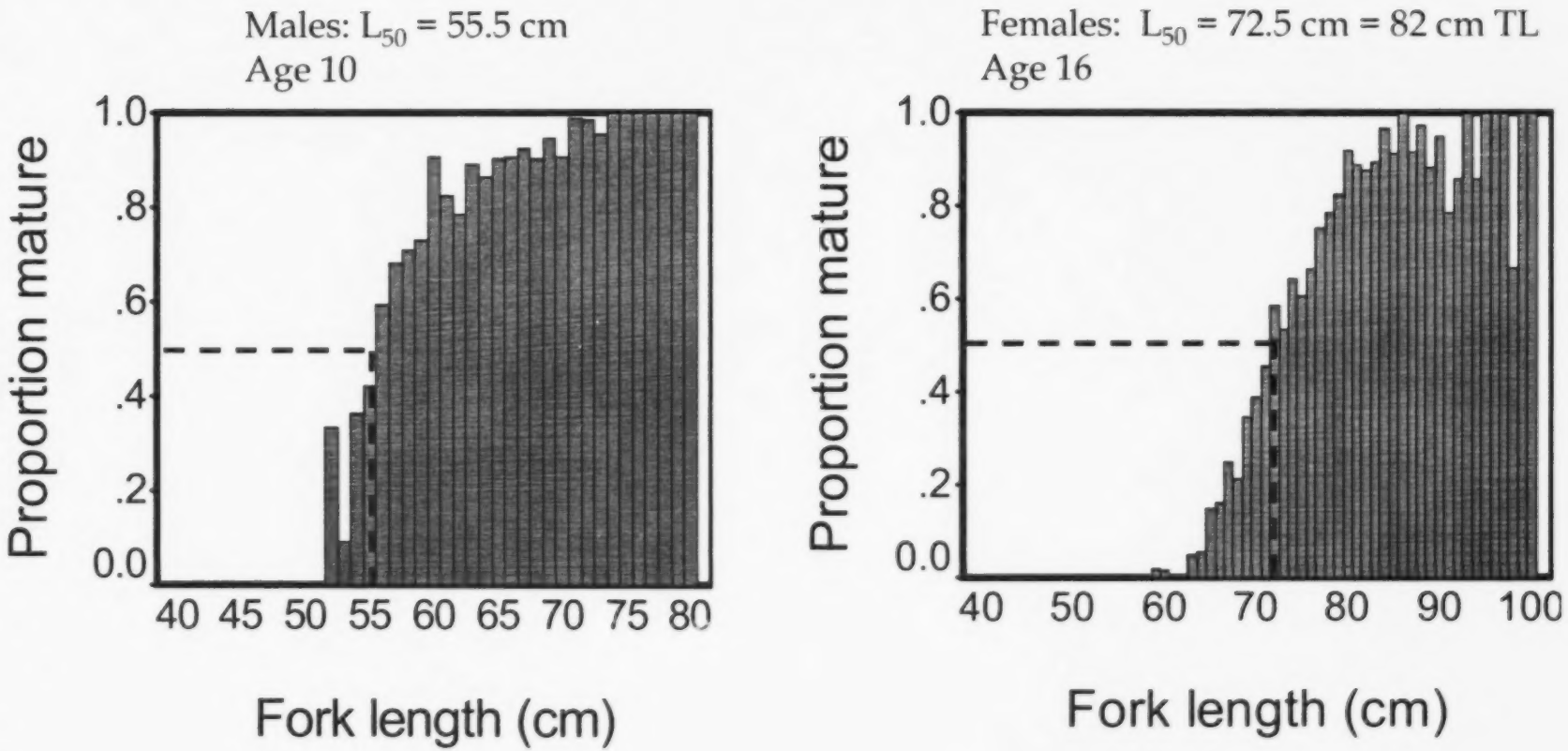


Fig. 4. Maturity ogives for male (n=1723) and female (n=3101) spiny dogfish off southwest Nova Scotia. Dashed lines show the fork length at 50% maturity (L_{50}) as defined by logistic regression.

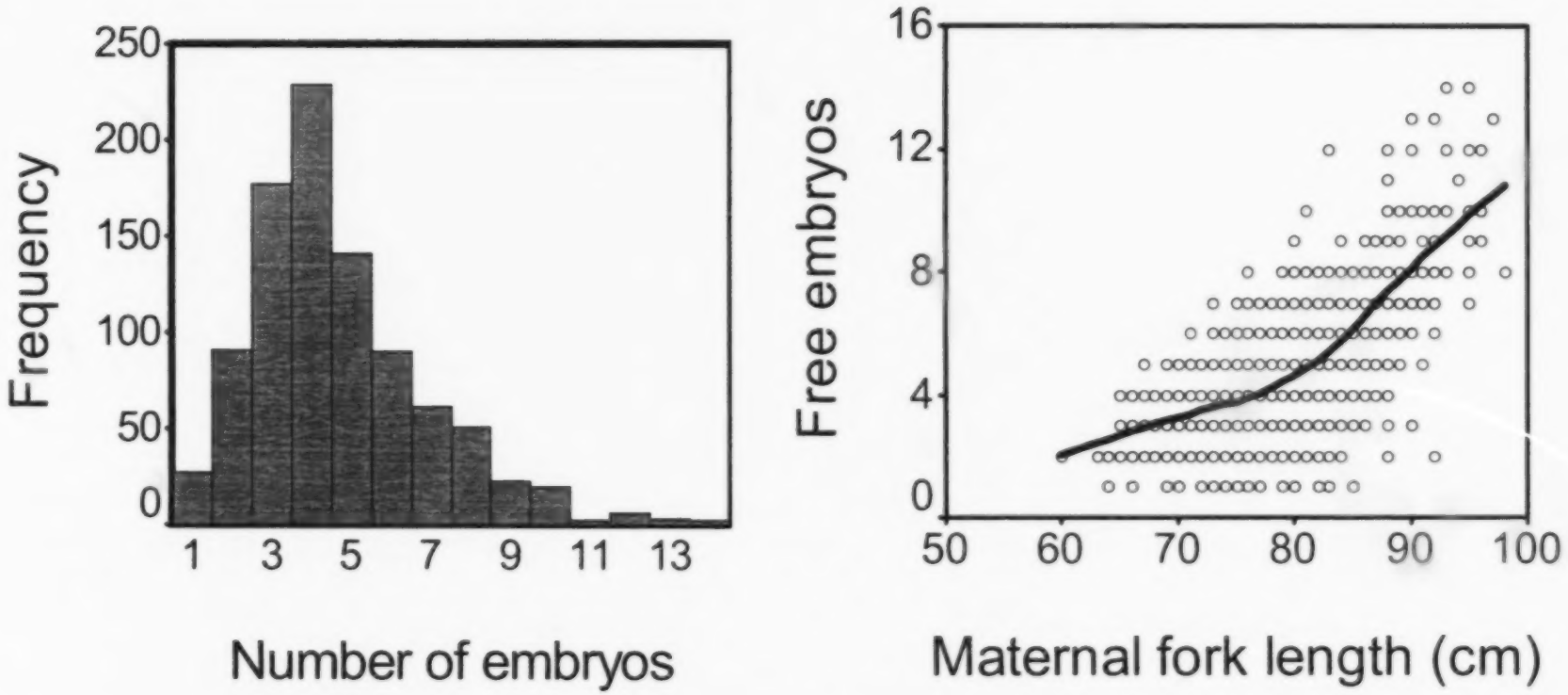
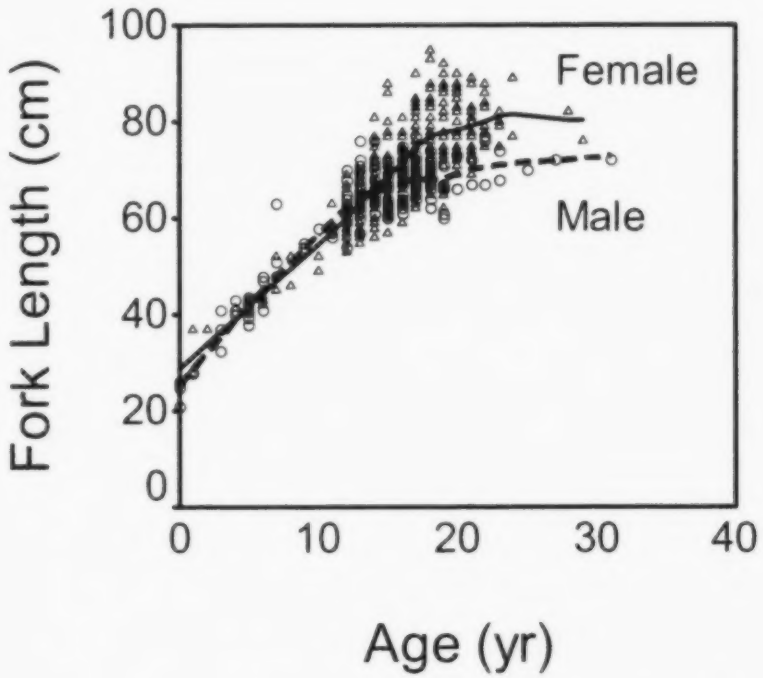


Fig. 5. Fecundity in spiny dogfish. (Left) Frequency distribution of free embryo number present in gravid females. (Right) The relationship between the number of free embryos and maternal fork length (n=907). A loess regression (solid line) has been fit to the data.

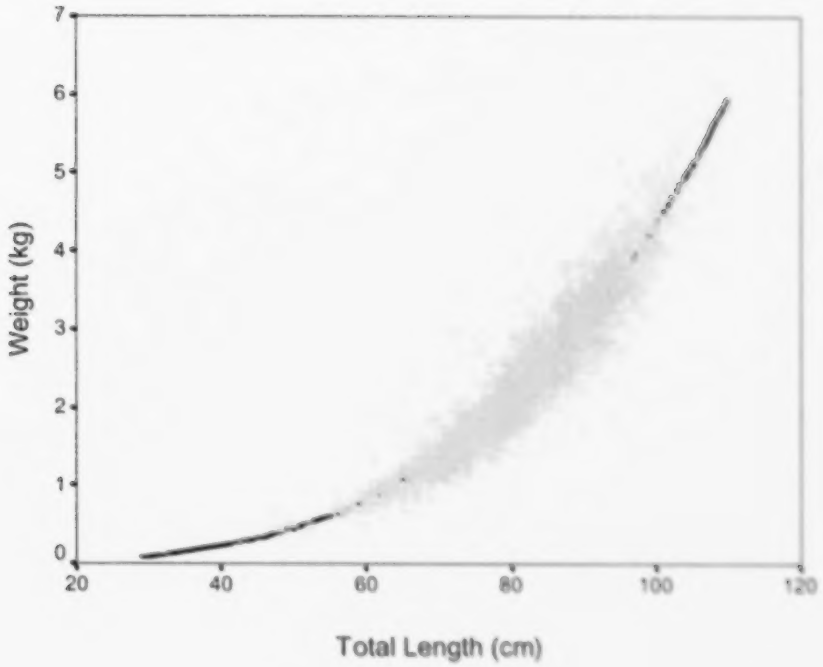


$L_t = L_\infty - (L_\infty - Lo)e^{-Kt}$

where

L_∞ = 78.0 and K = 0.099 for the males,
L_∞ = 119.5 and K = 0.042 for the females

Fig. 6. Length at age of male (circle) and female (triangle) spiny dogfish off southwest Nova Scotia (n=525). Loess regressions have been fit to the data for each sex.



$W = 0.0000013 \cdot TL^{3.2695}$ $R^2=0.91$

Fork Length = -1.5 + 0.90 • TL
Total Length = 3.1 + 1.09 • FL

Fig. 7. Relationship between live weight and total length (straight measure), and between two measures of length, in spiny dogfish.

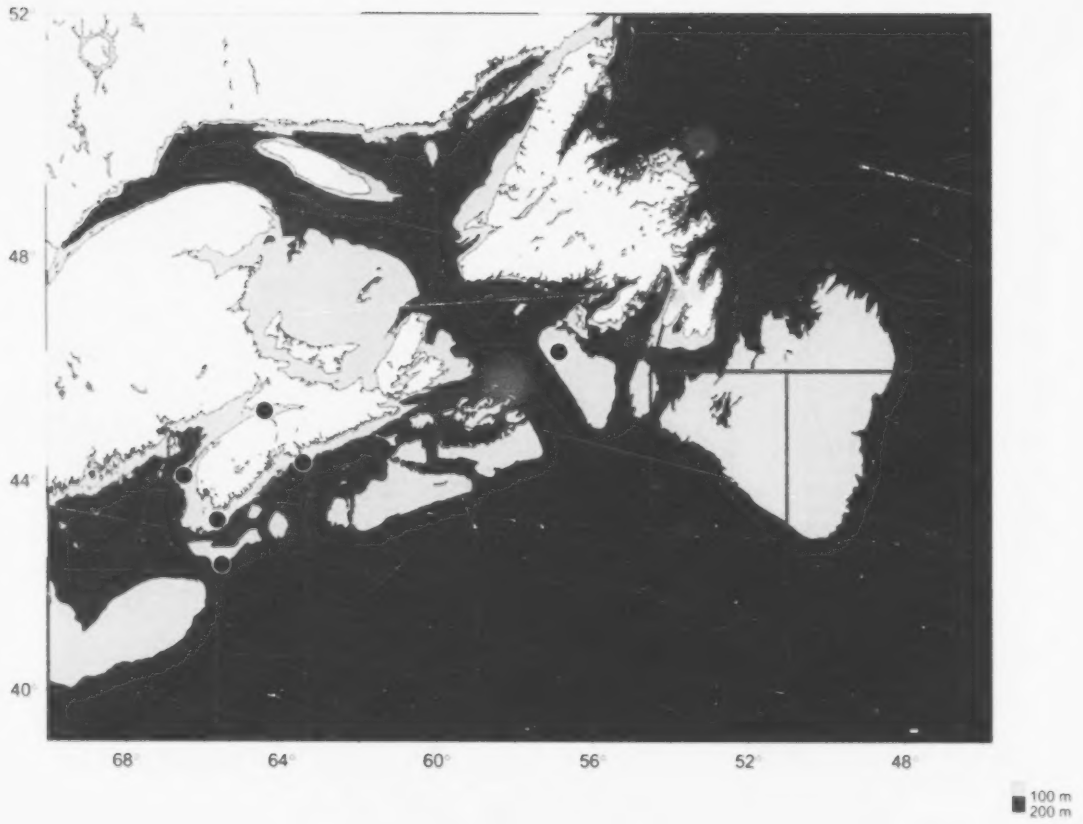
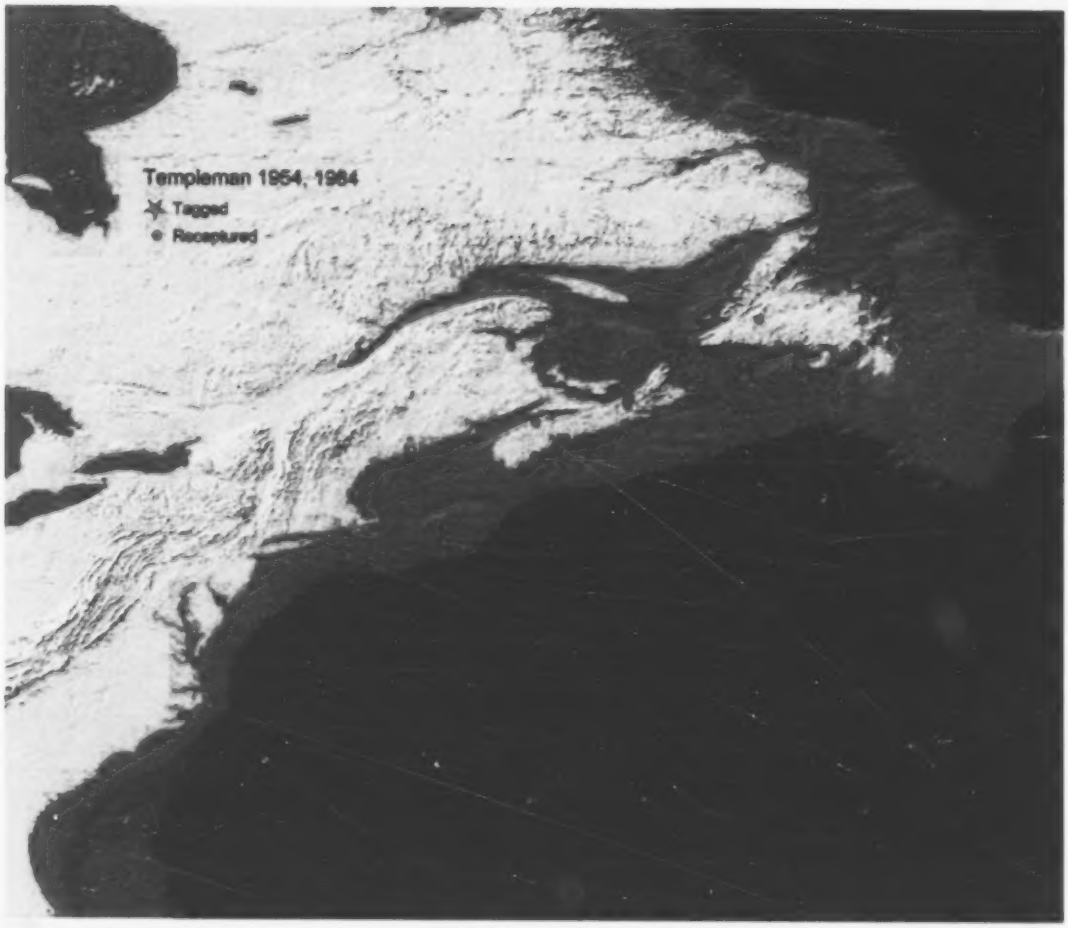
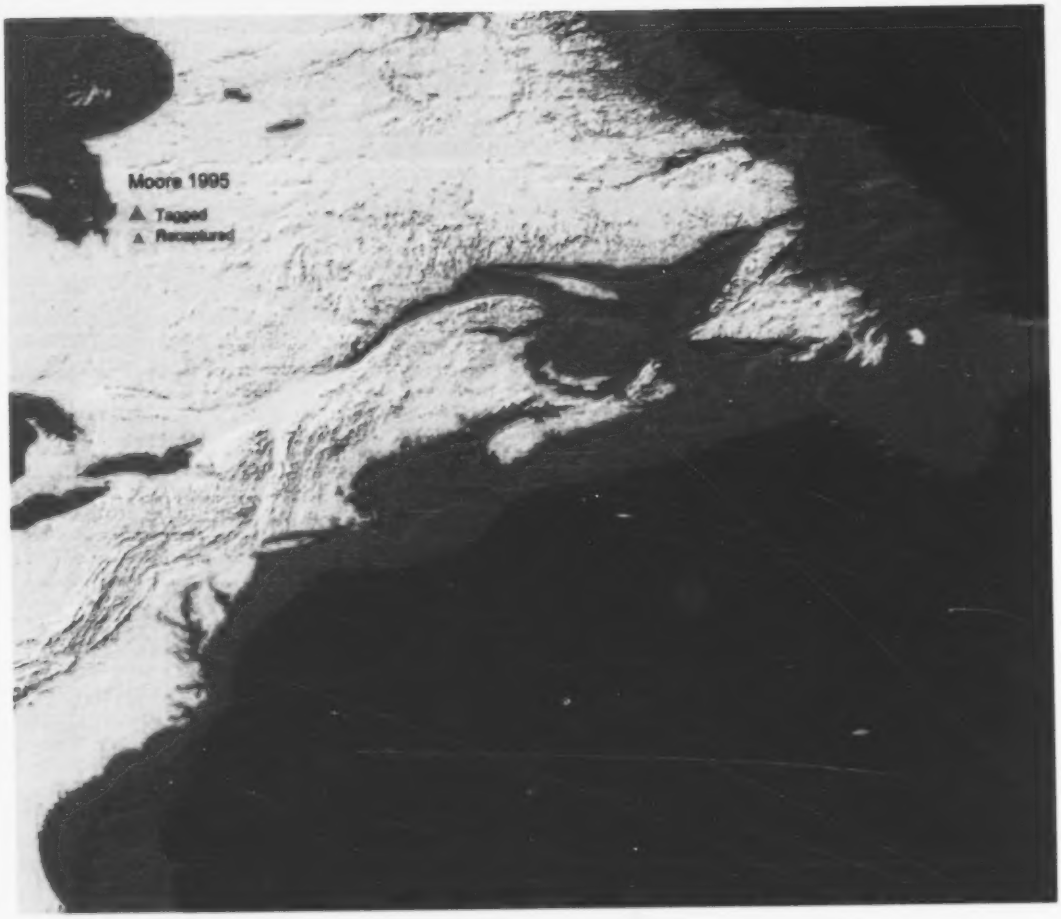


Fig. 8. Location of dogfish samples (n=307) analyzed for microsatellite DNA.



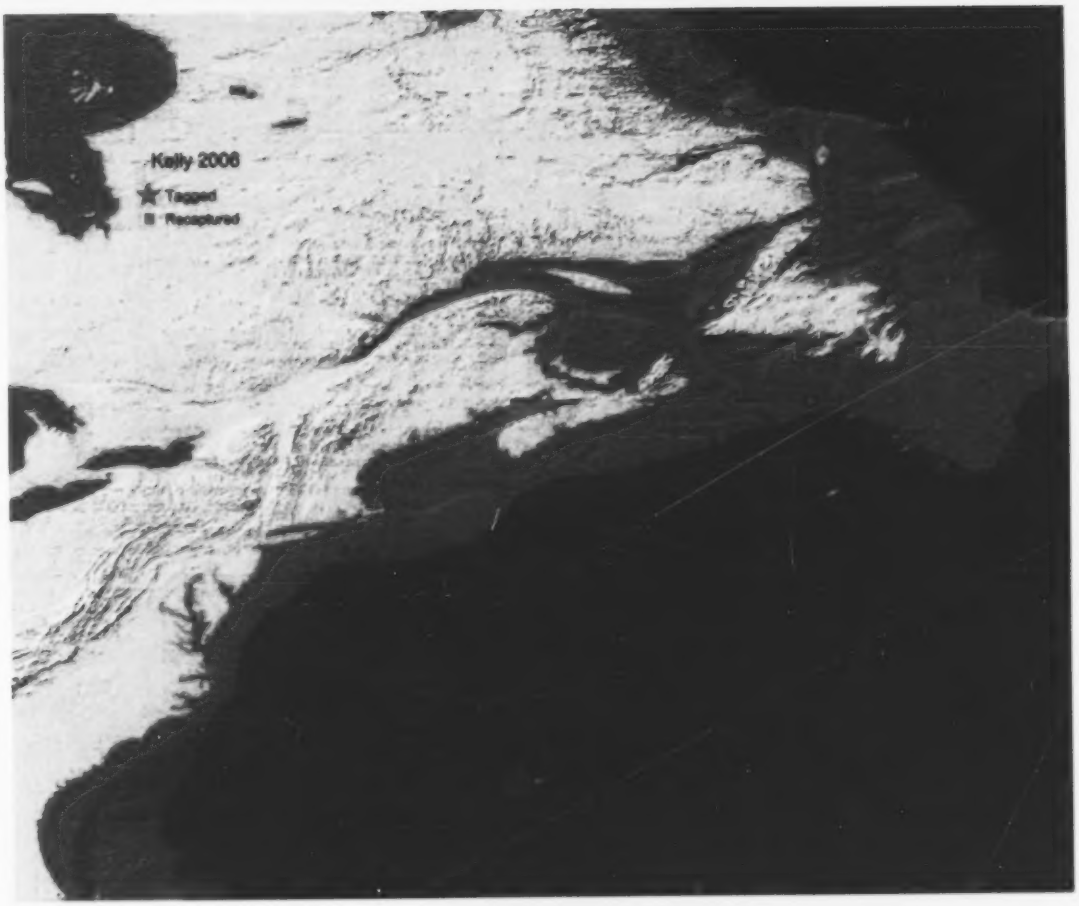
N = 2657 tagged
N = 232 recaptured

Fig 9. Distribution of spiny dogfish tag recaptures from the studies of Templeman (1954, 1984). Not all of the 200+ recaptures made in Newfoundland waters are shown.



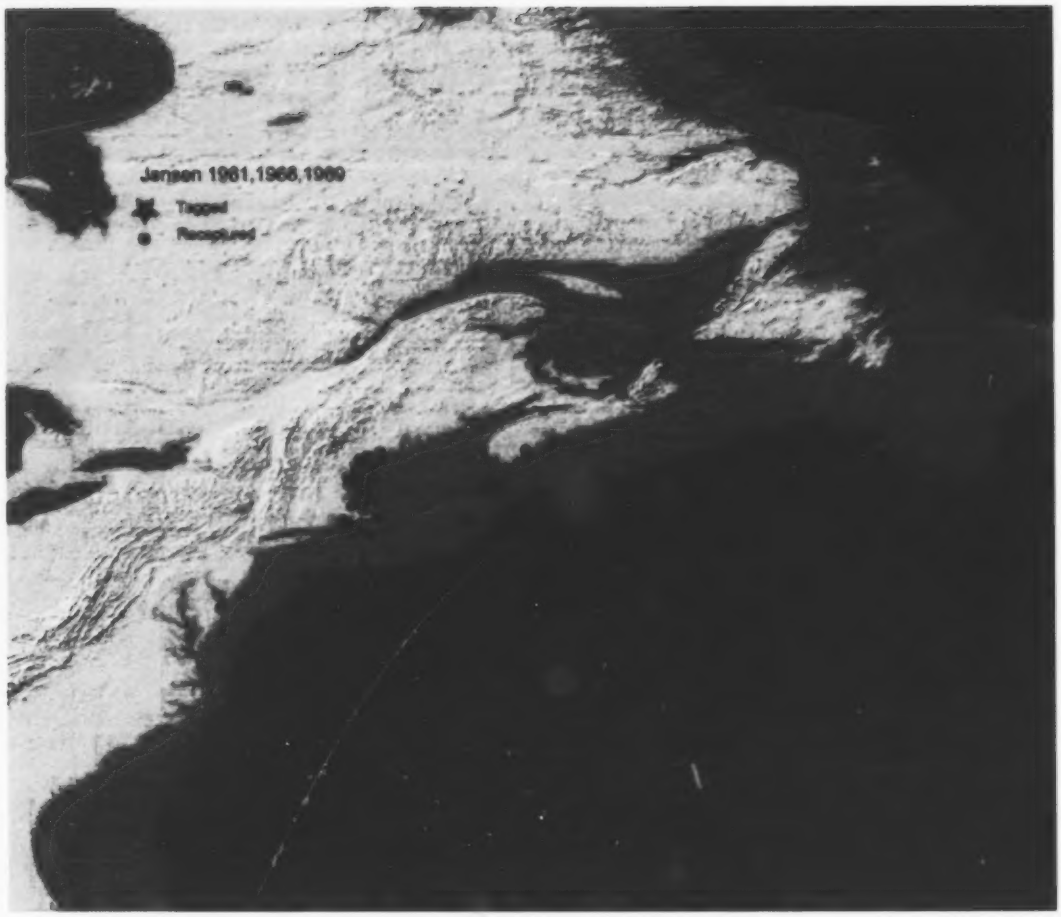
N = 995 tagged
N = 39 recaptured

Fig 10. Distribution of spiny dogfish tag recaptures from the studies of Moore (1998, unpublished).



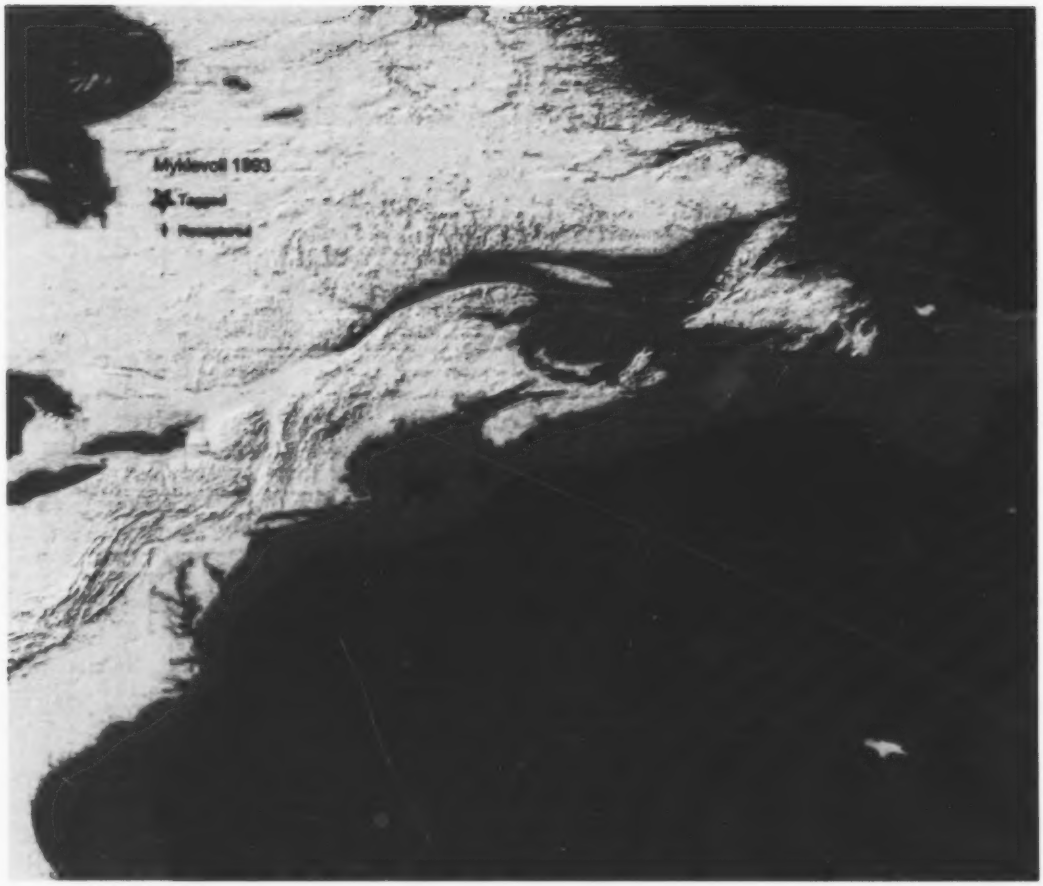
N = 743 tagged
N = 10 recaptured

Fig 11. Distribution of spiny dogfish tag recaptures from the studies of Kelly (unpublished 2005, 2006).



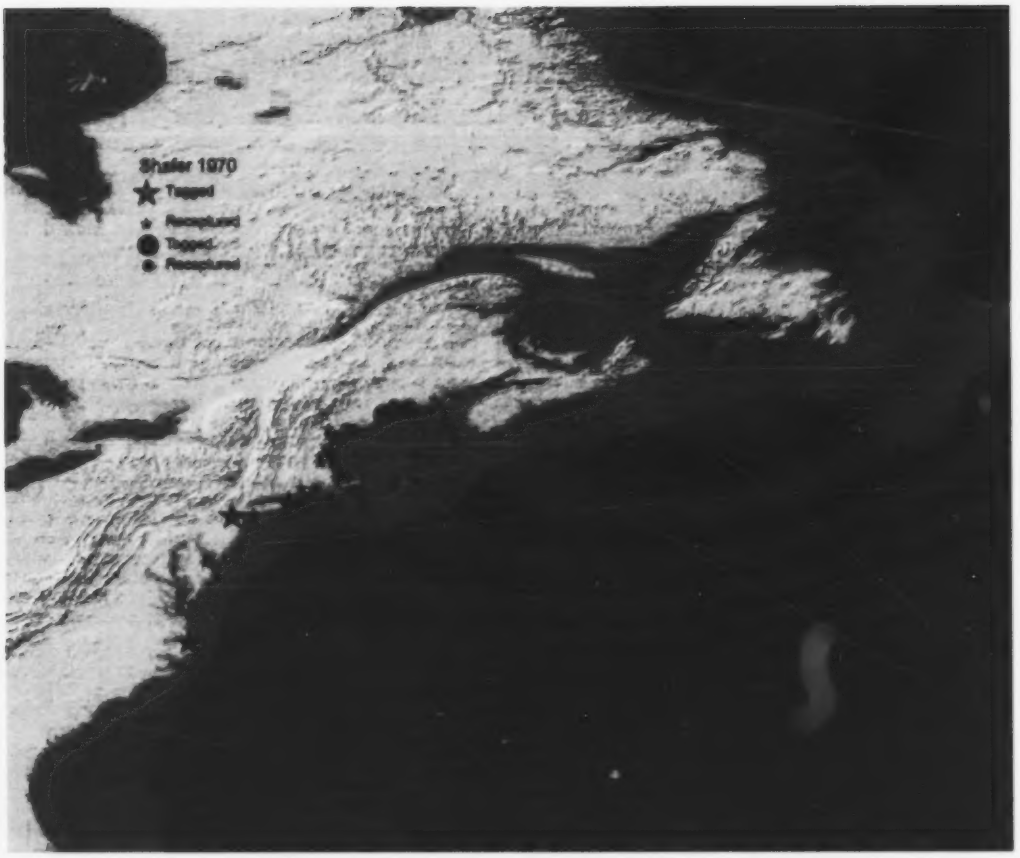
N = 999 tagged
N = 25 recaptured

Fig 12. Distribution of spiny dogfish tag recaptures from the studies of Jensen (1961, 1966, 1969).



N = 500 tagged
N = 14 recaptured

Fig 13. Distribution of spiny dogfish tag recaptures from the studies of Myklevoll (1993).



N = 3583 tagged
N = 60 recaptured

Fig 14. Distribution of spiny dogfish tag recaptures from the studies of Shafer (1970).

N = 36604 tagged
N = 285 recaptured

Fig 15. Distribution of spiny dogfish tag recaptures from Rulifson (unpublished).

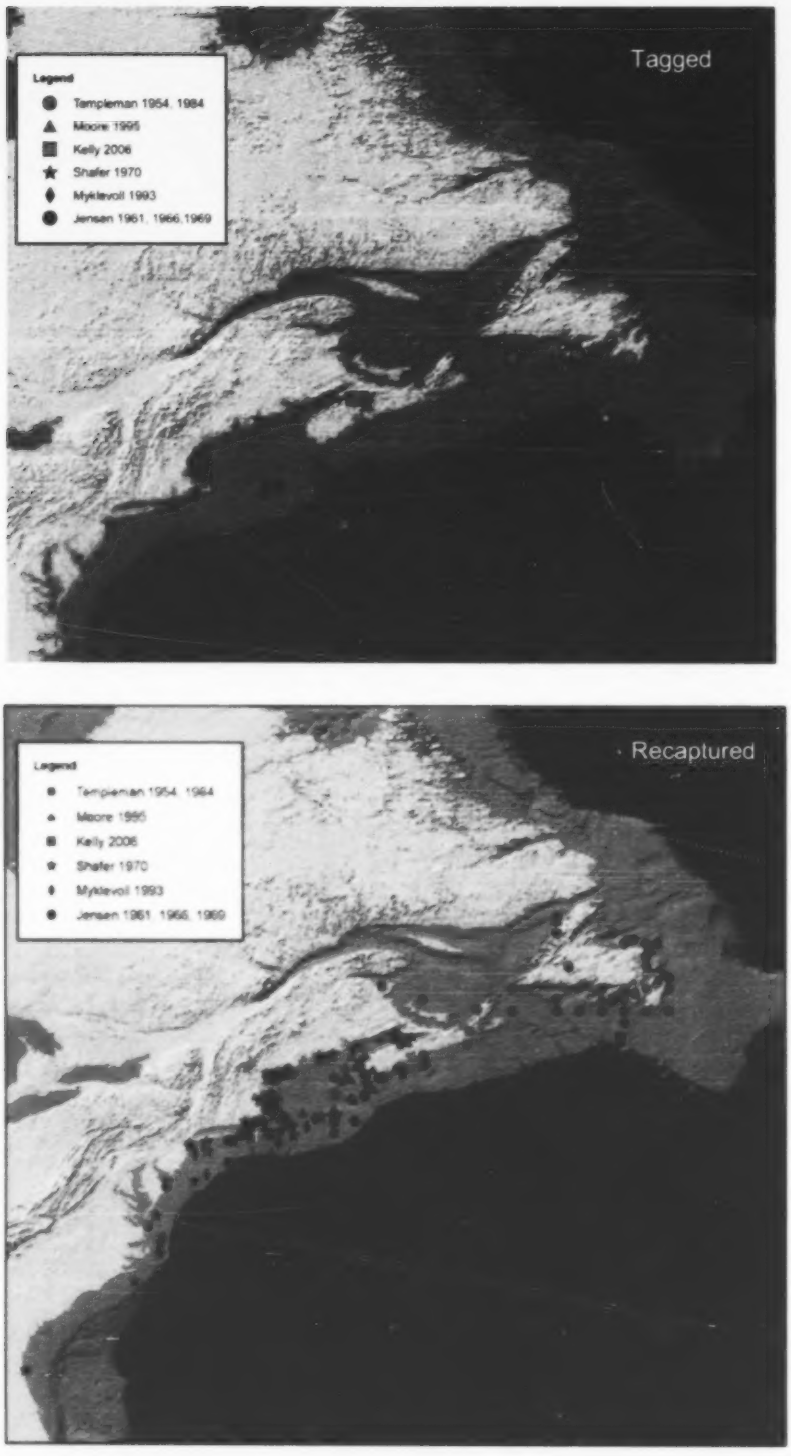


Fig 16. Distribution of spiny dogfish tag recaptures from all studies except those of Rulifson (unpublished). Tags applied in Canadian waters are shown in red, while those applied in U.S. waters are shown in blue.

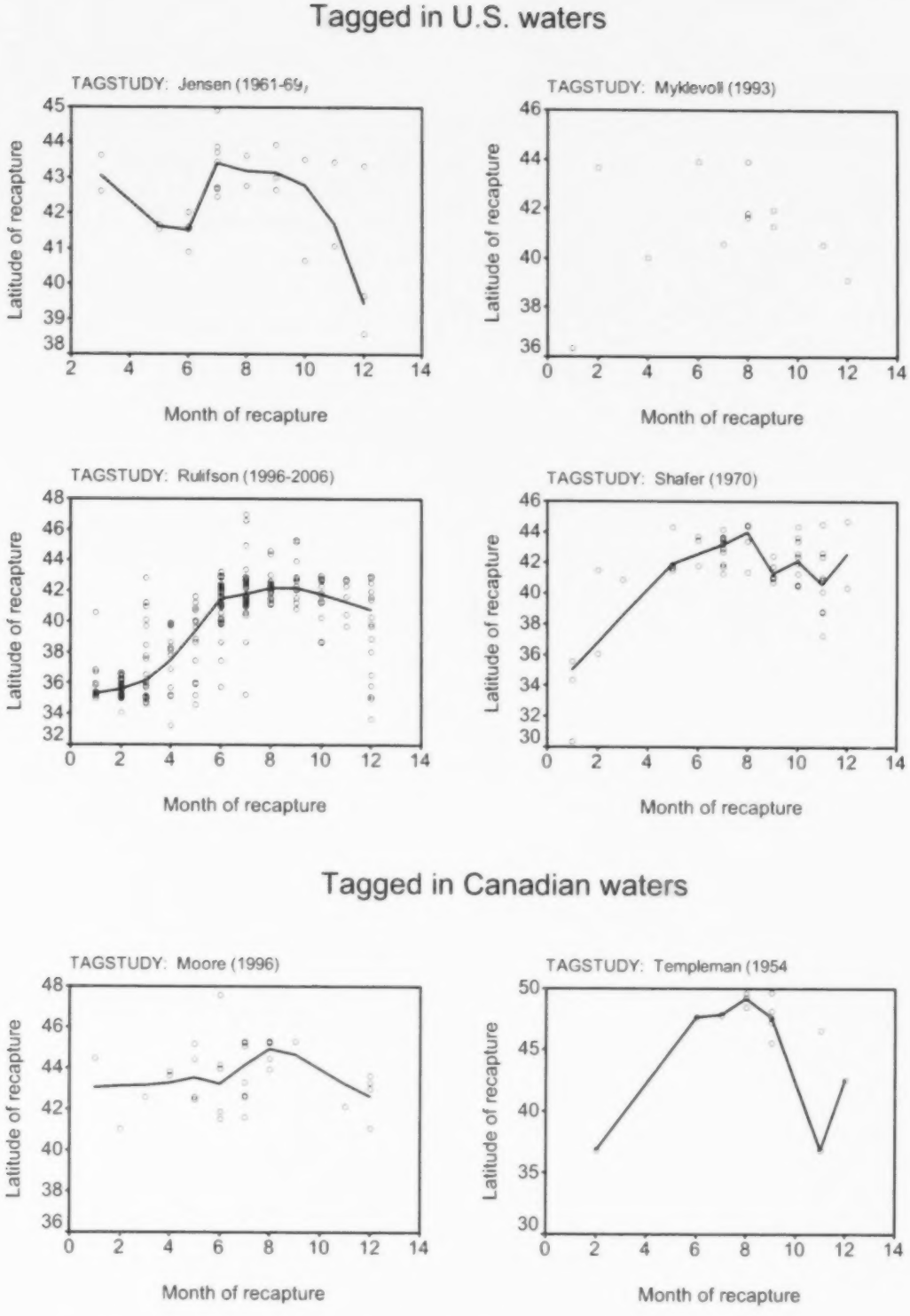


Fig 17. Seasonal migration of spiny dogfish in individual tagging studies as inferred from latitude of recapture. A loess curve has been fit to the data.

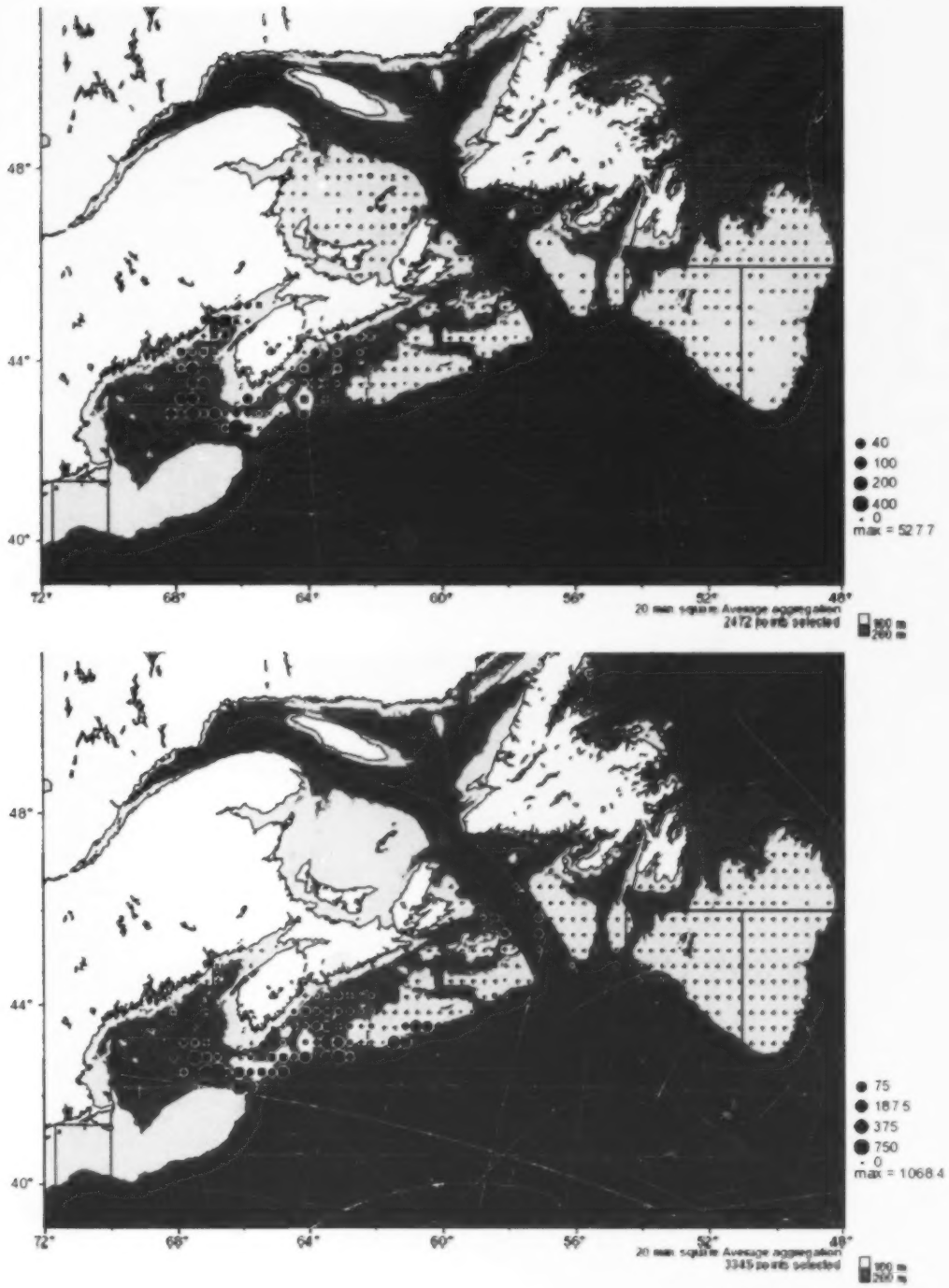


Fig. 18. Summer (top) and spring (bottom) distributions of spiny dogfish in RV surveys of the Scotian Shelf (1979-84), Newfoundland (1979-84) and southern Gulf of St. Lawrence (1985). Dogfish move to deeper, offshore waters in the winter and spring, but there is no mass migration out of Canadian waters.

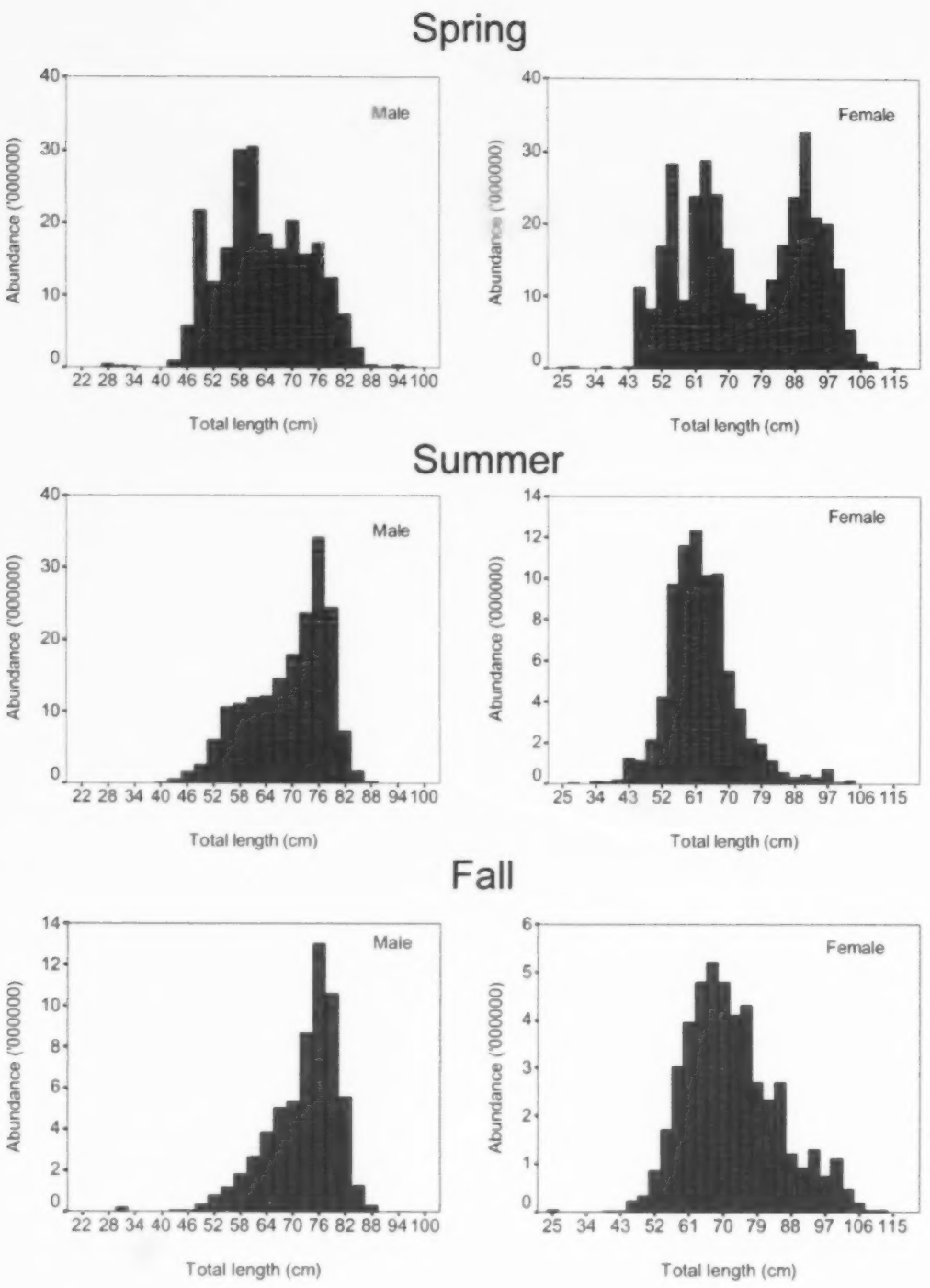


Fig. 19. Spring, summer and fall length frequency distributions of spiny dogfish in RV surveys of the Scotian Shelf between 1979-84, summed across years.

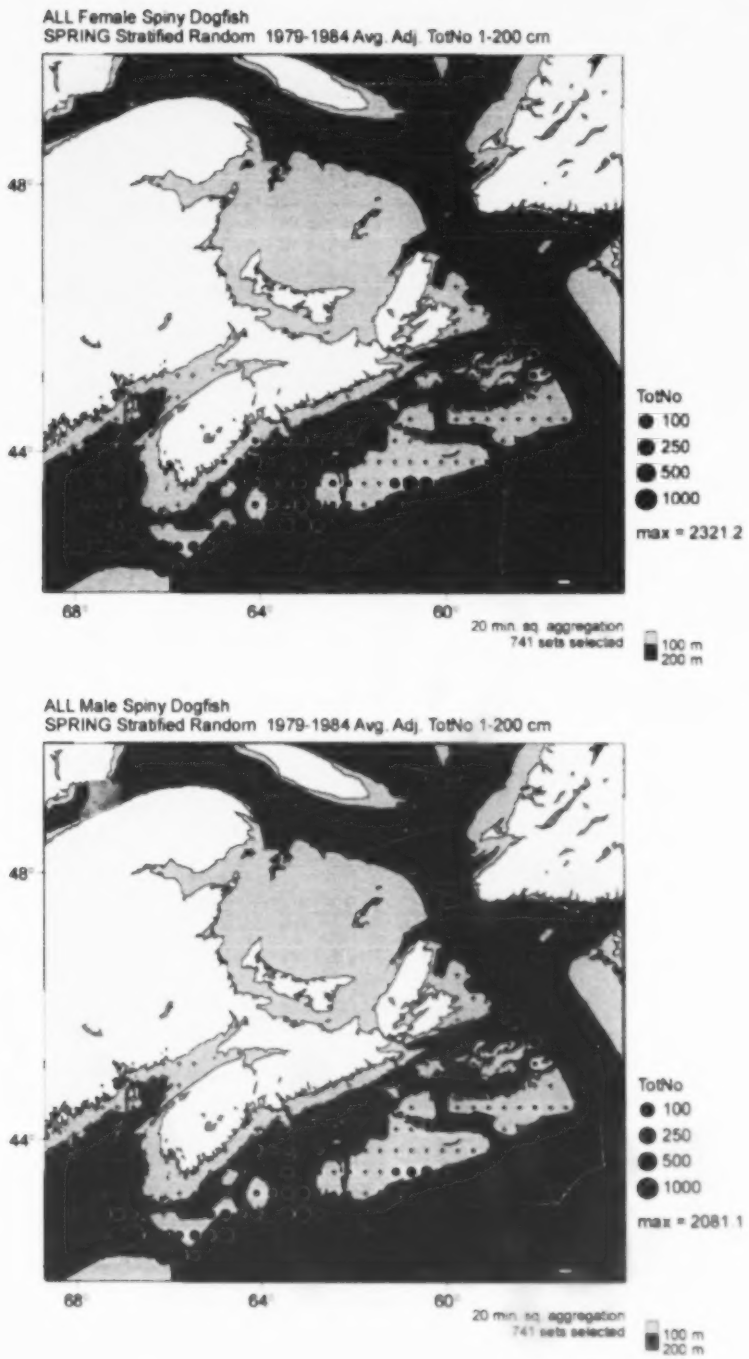


Fig. 20. Distribution of male and female spiny dogfish in spring RV surveys between 1979-1984. No spatial segregation by sex is evident.

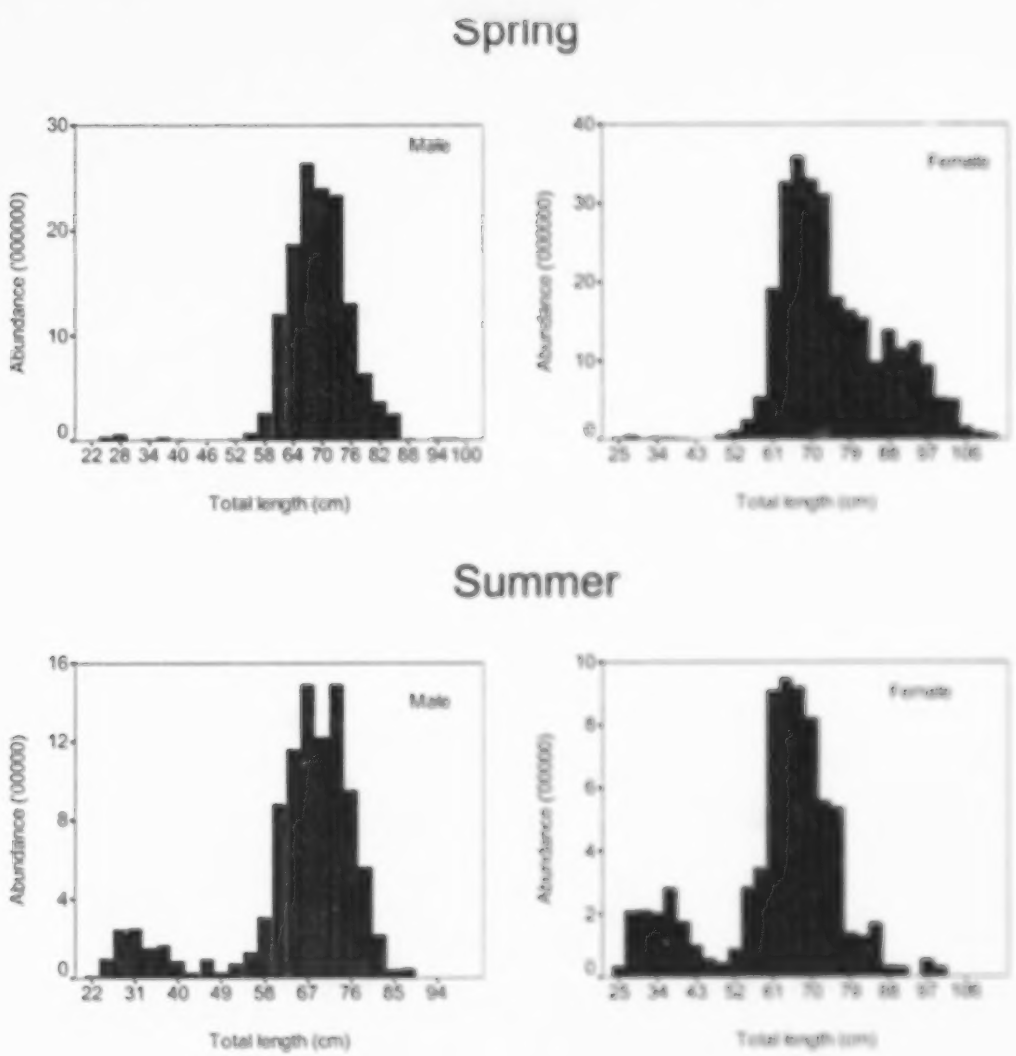


Fig. 21. Spring (top) and summer (bottom) length frequency distributions of spiny dogfish in RV surveys of the Eastern Scotian Shelf (4VW) between 1986-91, summed across years.

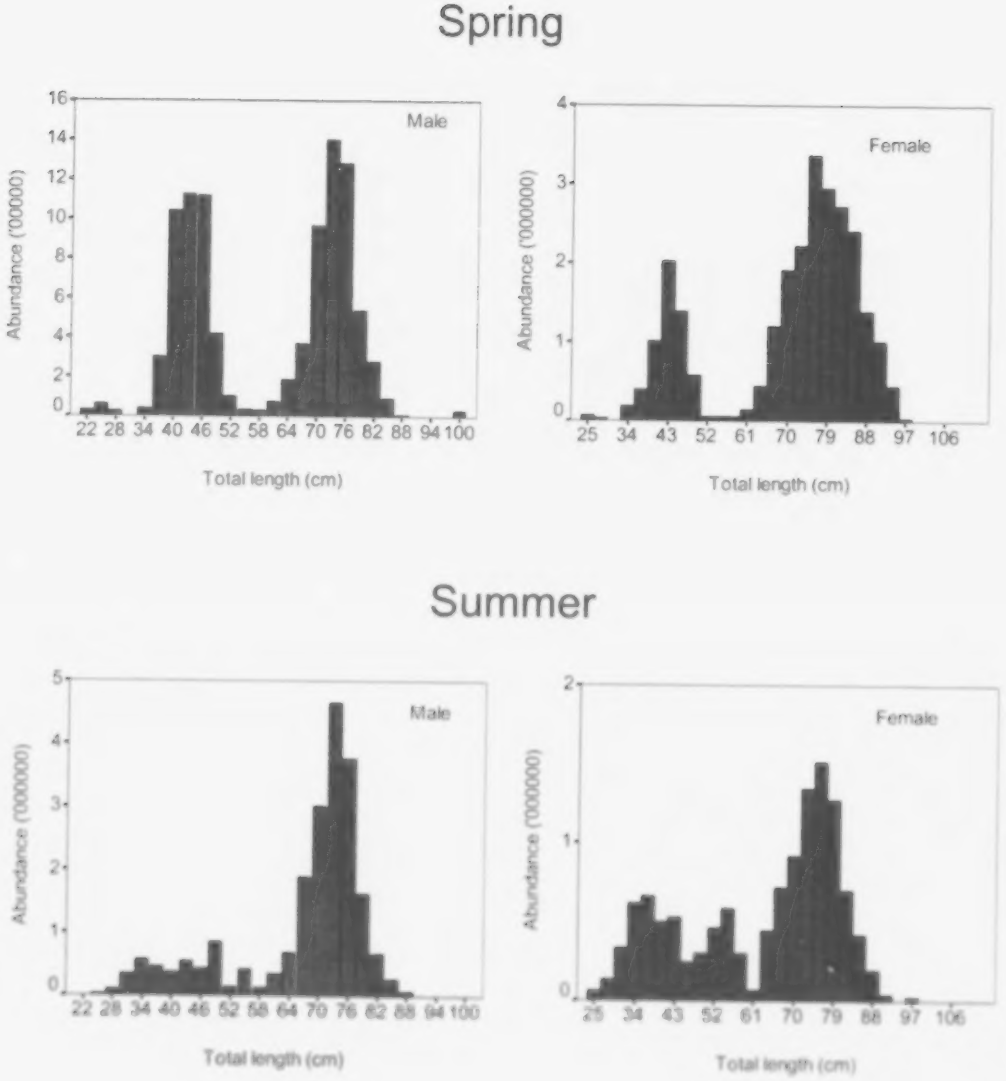


Fig. 22. Spring (top) and summer (bottom) length frequency distributions of spiny dogfish in RV surveys of the Eastern Scotian Shelf (4VW) between 1994-2003, summed across years.

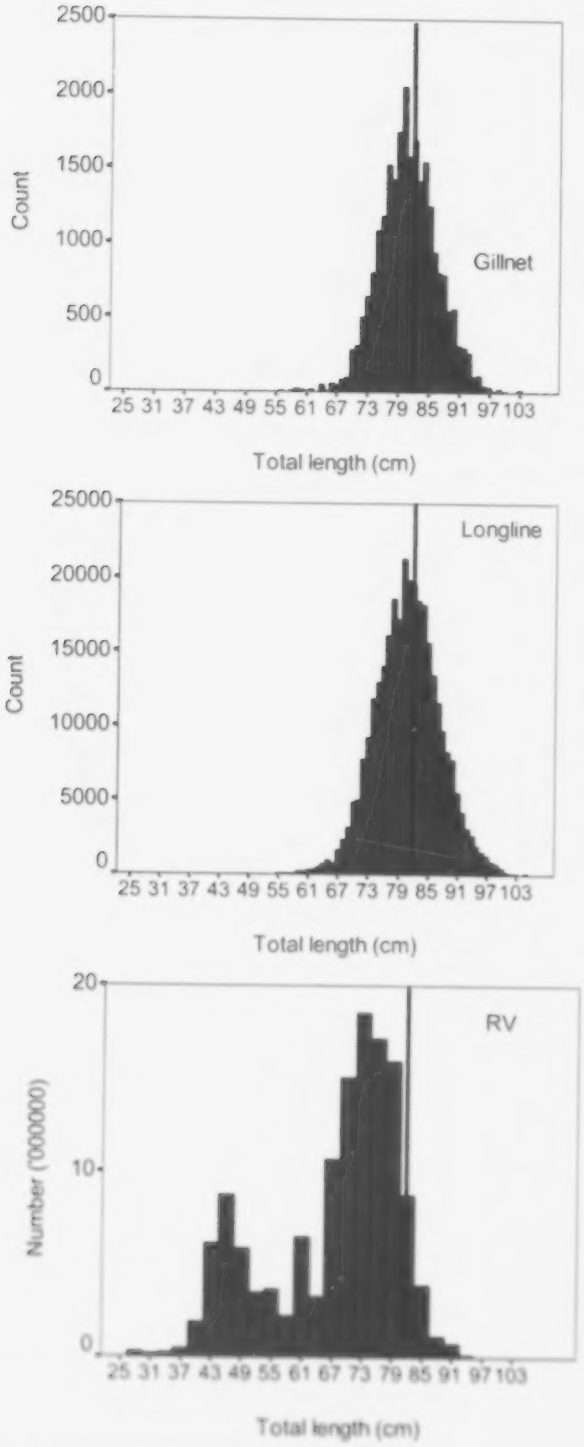


Fig. 23. Summer length frequency distributions of female spiny dogfish in 4X in RV surveys compared to longline and gillnet catch between 2002 and 2006, summed across years. The vertical line indicates the length at female maturity (L_{50}). Commercial catches do not reflect the presence of small juvenile fish, while the RV catch under-represents the abundance of large females.

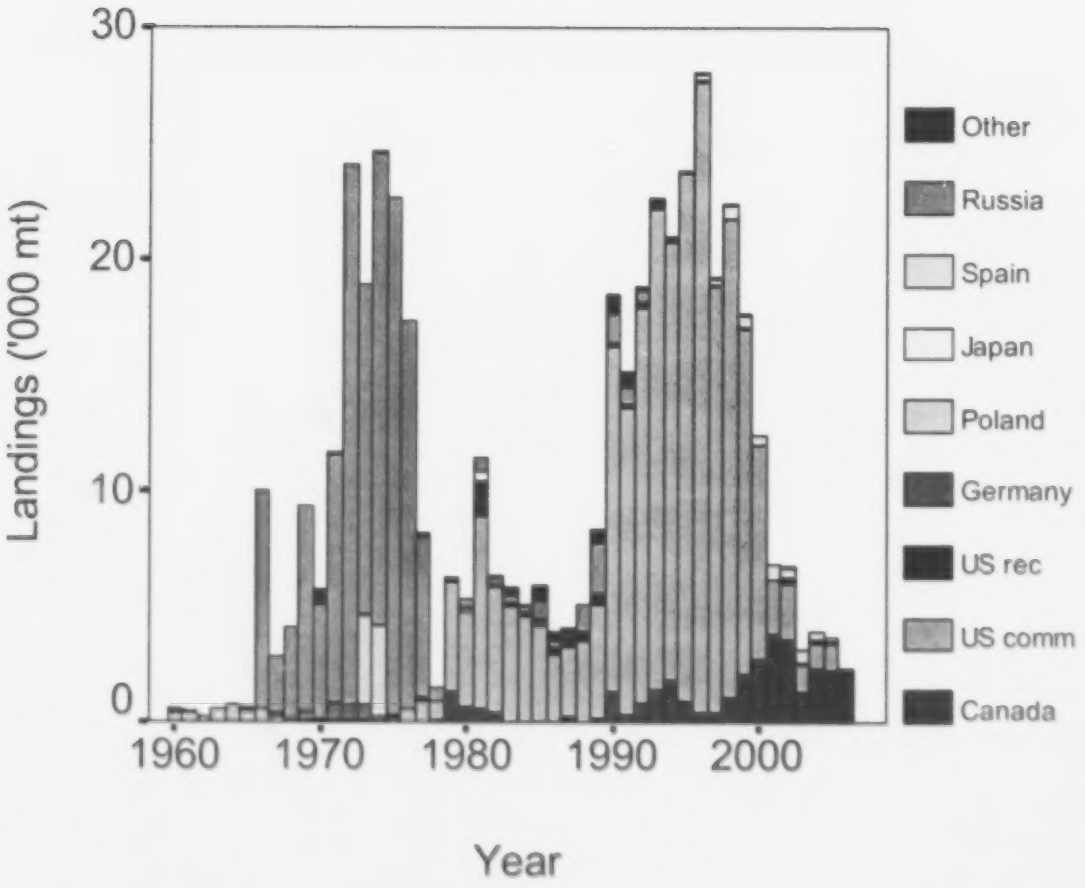


Fig. 24. Reported landings of spiny dogfish by country by year in NAFO Areas 2-6.

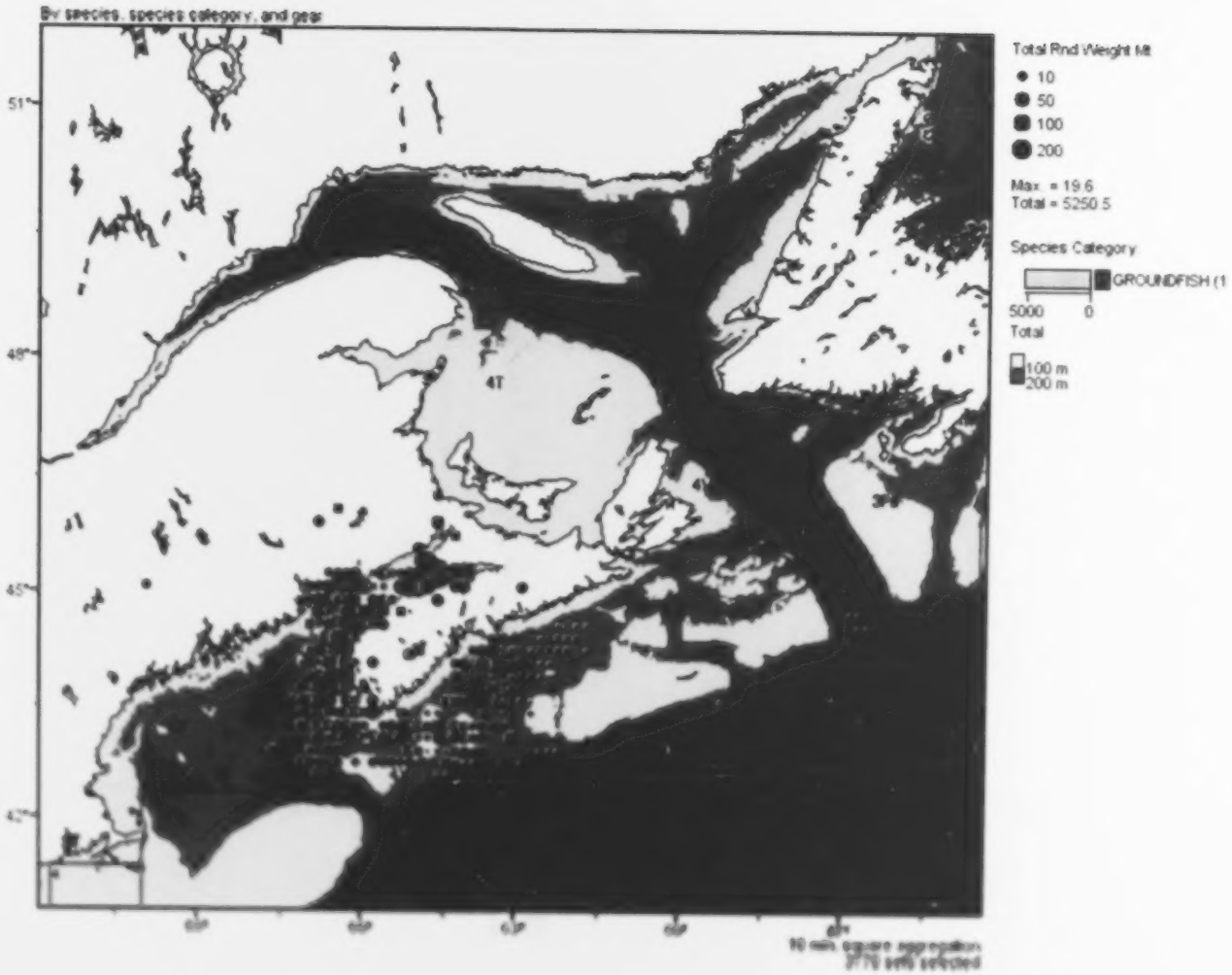


Fig. 25. Landings of spiny dogfish in Scotia-Fundy as recorded in MARFIS.

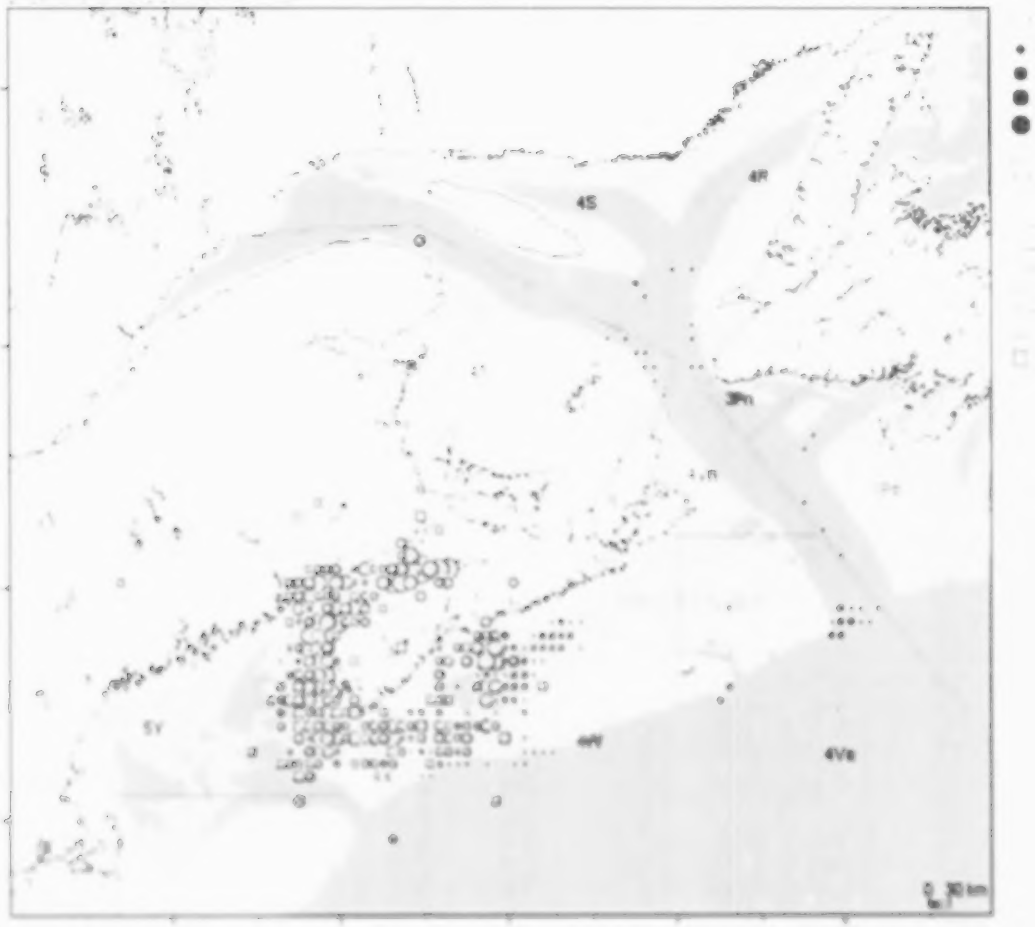


Fig. 25. Landings of spiny dogfish in Scotia-Fundy as recorded in MARFIS

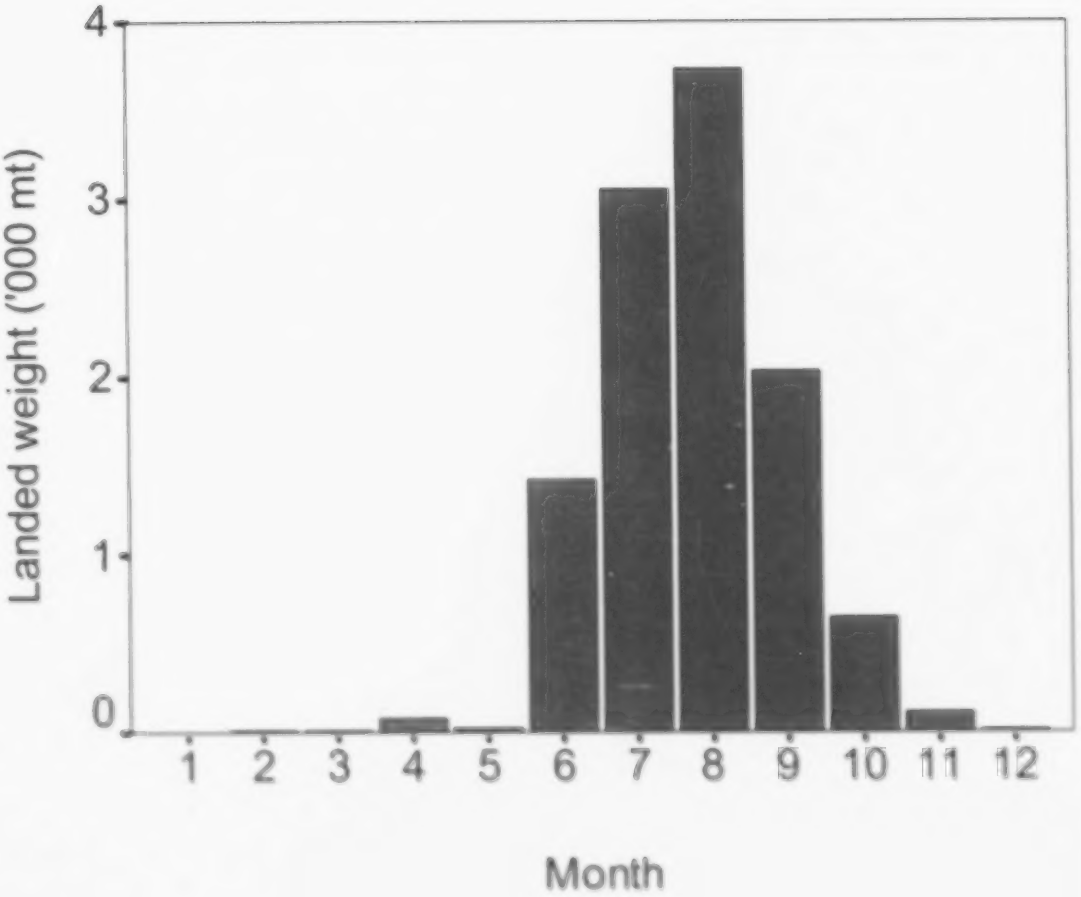


Fig. 26. Scotia-Fundy landings by month between 2002-2006.

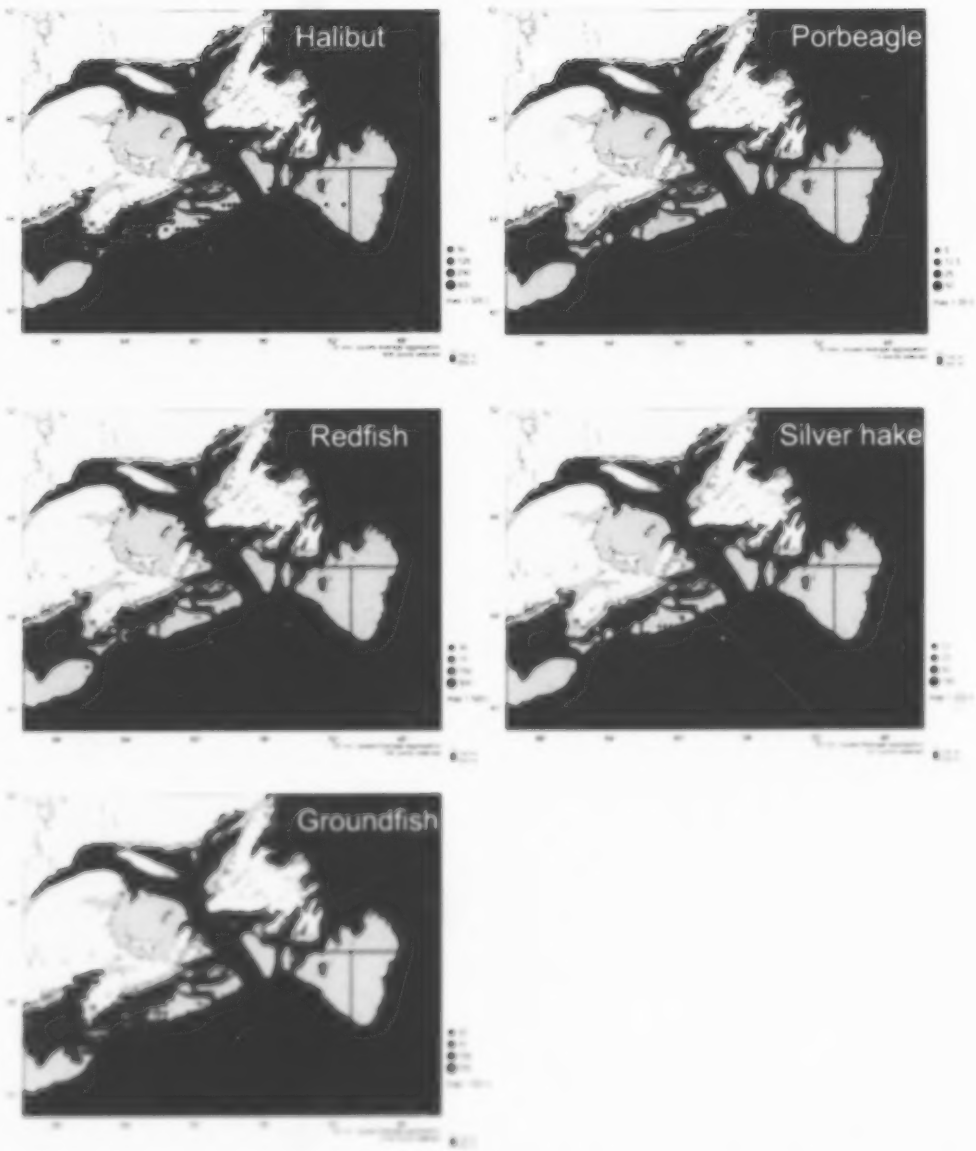


Fig. 27. Bycatch distribution of spiny dogfish by fishery between 2002-2006 as recorded by observers.

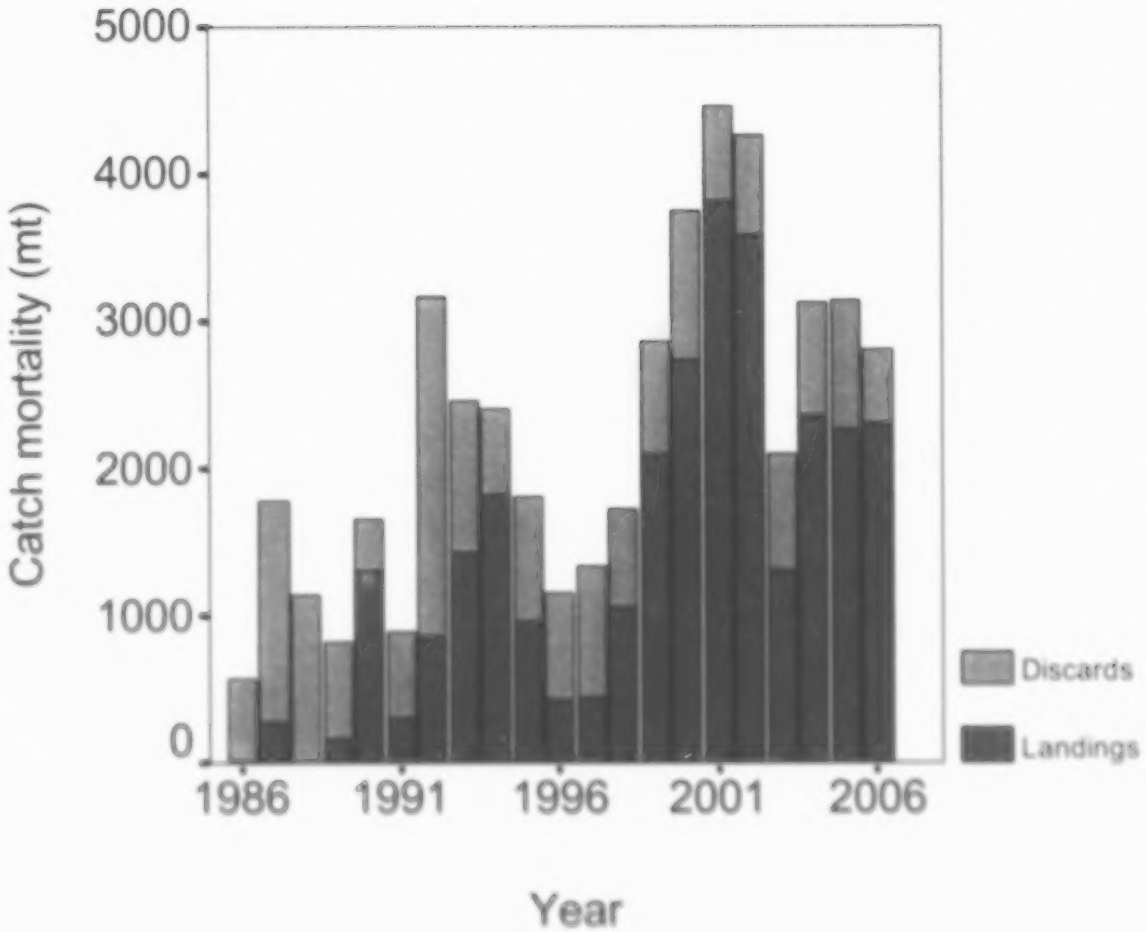


Fig. 28. Total catch and discard mortality of spiny dogfish caught in Canadian waters since 1986.

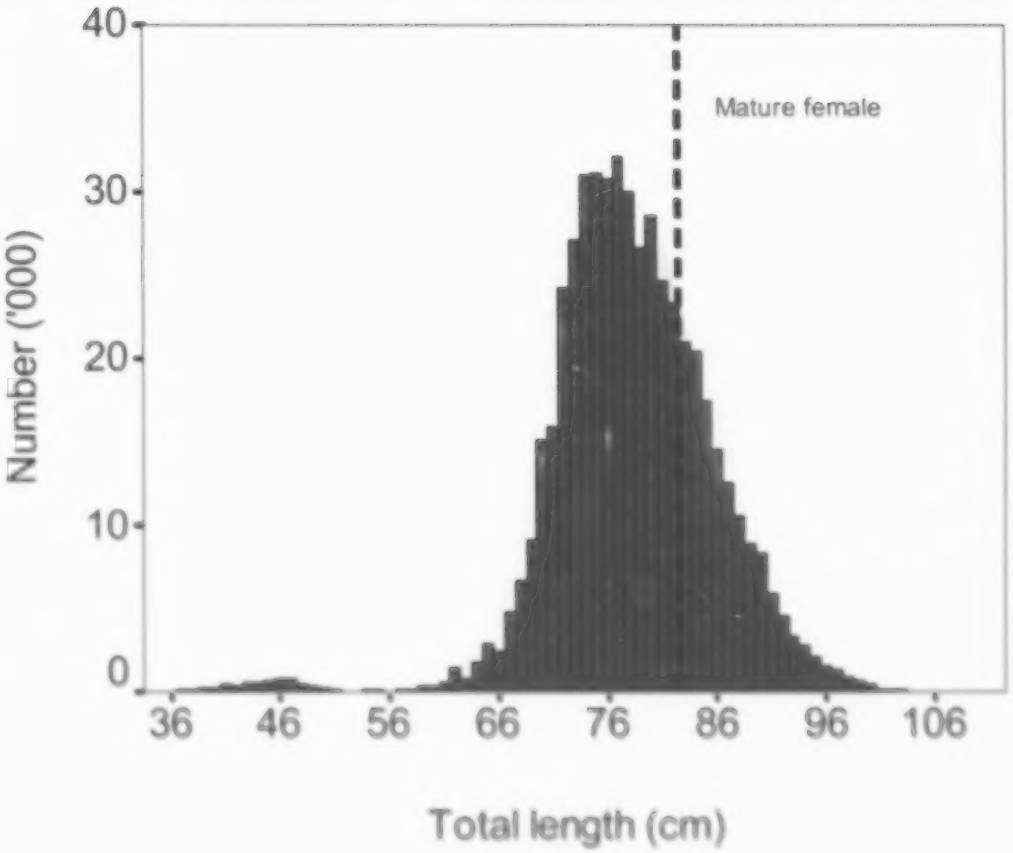


Fig. 29. Size composition of the commercial catch in 4X between 2002-2006, aggregated by sex. The dashed line indicates the size corresponding to female 50% maturity; almost all of the catch (26%) exceeding that size is female.

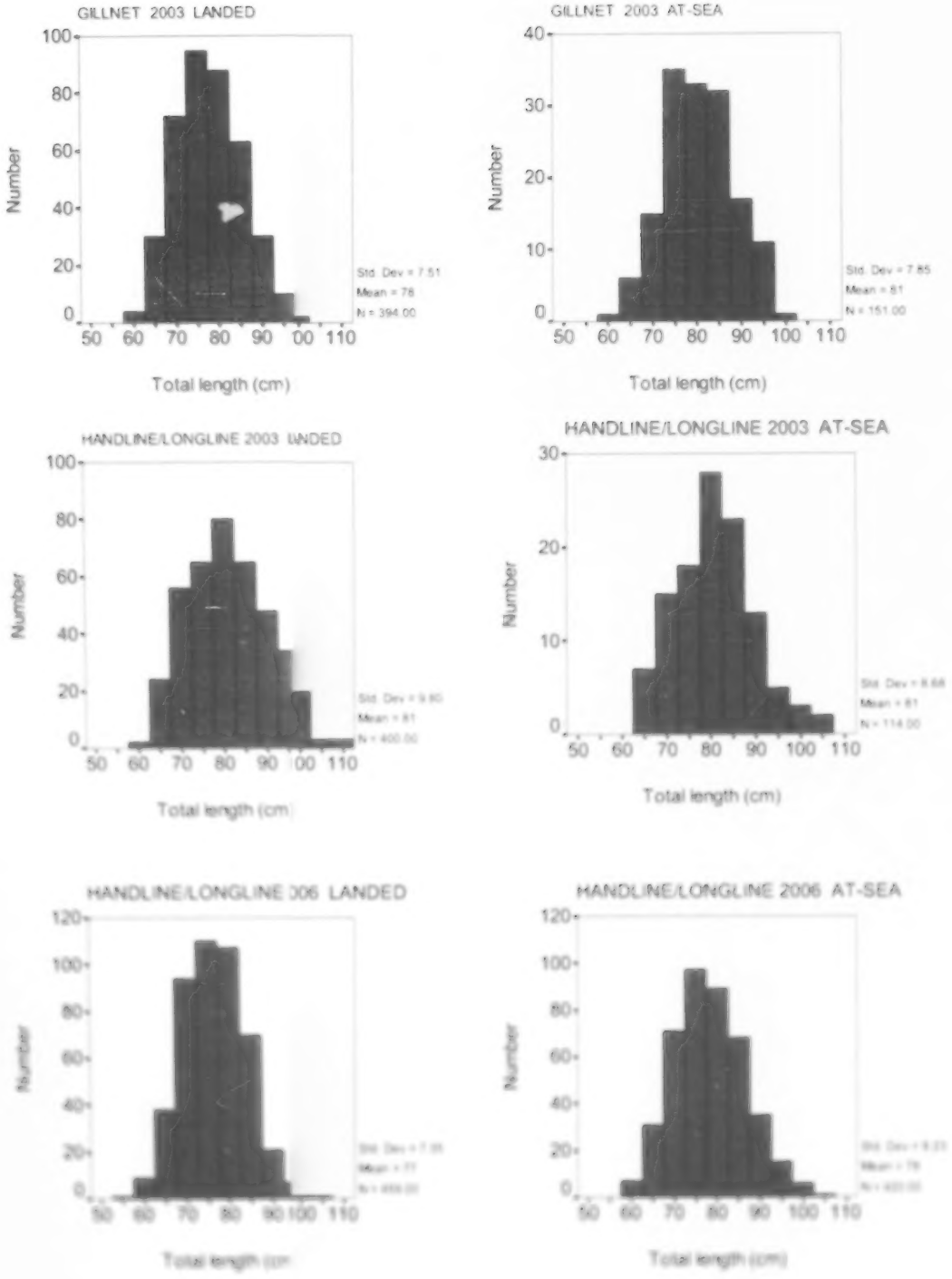
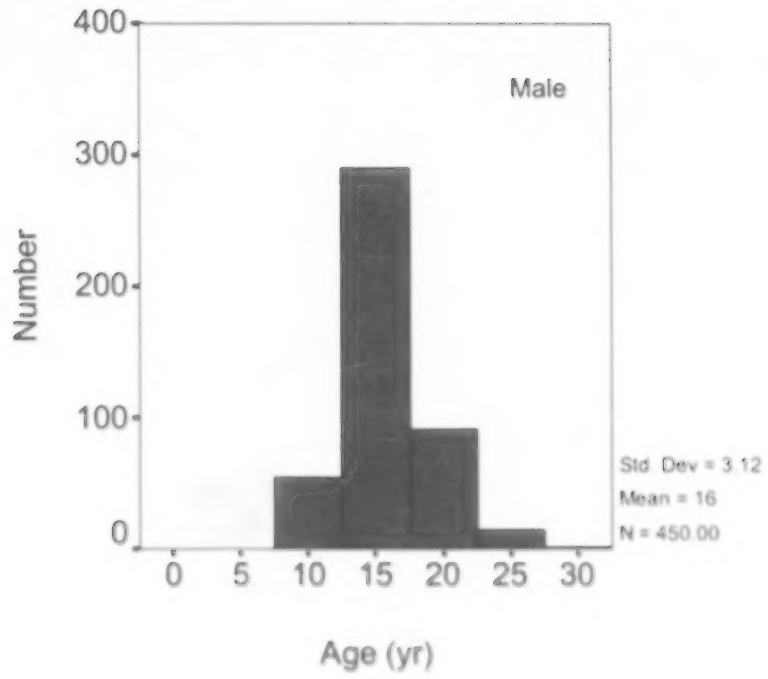


Fig. 30. Commercial length frequencies of spiny dogfish by gear and year, split to test for differences between at-sea (before discarding) and landed values (after discarding). No highgrading by size was evident.



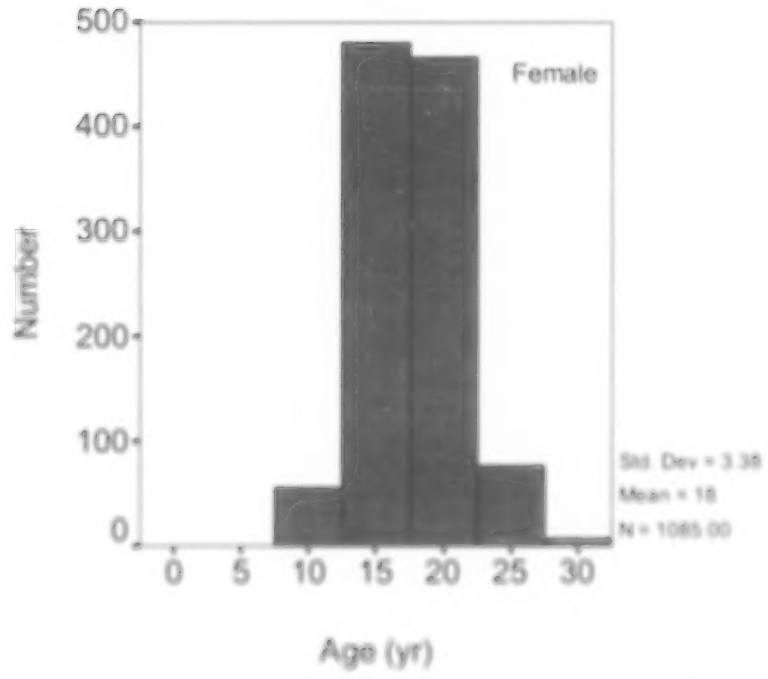


Fig. 31. Age composition by sex of the commercial catch in 4WX between 2003-2006.

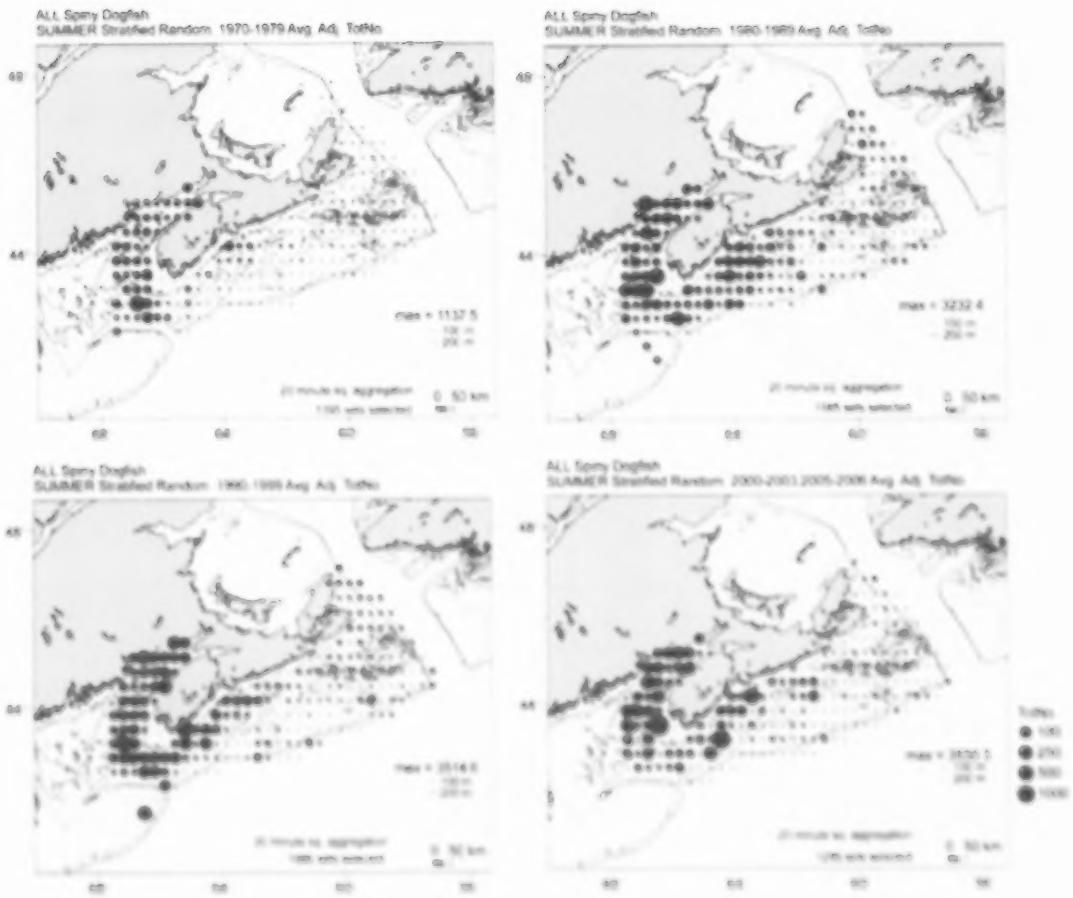

ALL Spiny Dogfish
SUMMER Stratified Random 1970-1979 Avg Adj Totno
ALL Spiny Dogfish
SUMMER Stratified Random 1980-1989 Avg Adj Totno
ALL Spiny Dogfish
SUMMER Stratified Random 1990-1999 Avg Adj Totno
ALL Spiny Dogfish
SUMMER Stratified Random 2000-2001,2005-2006 Avg Adj Totno

Fig 32. Distribution of spiny dogfish in summer RV surveys of the Scotian Shelf, 1970-2006.

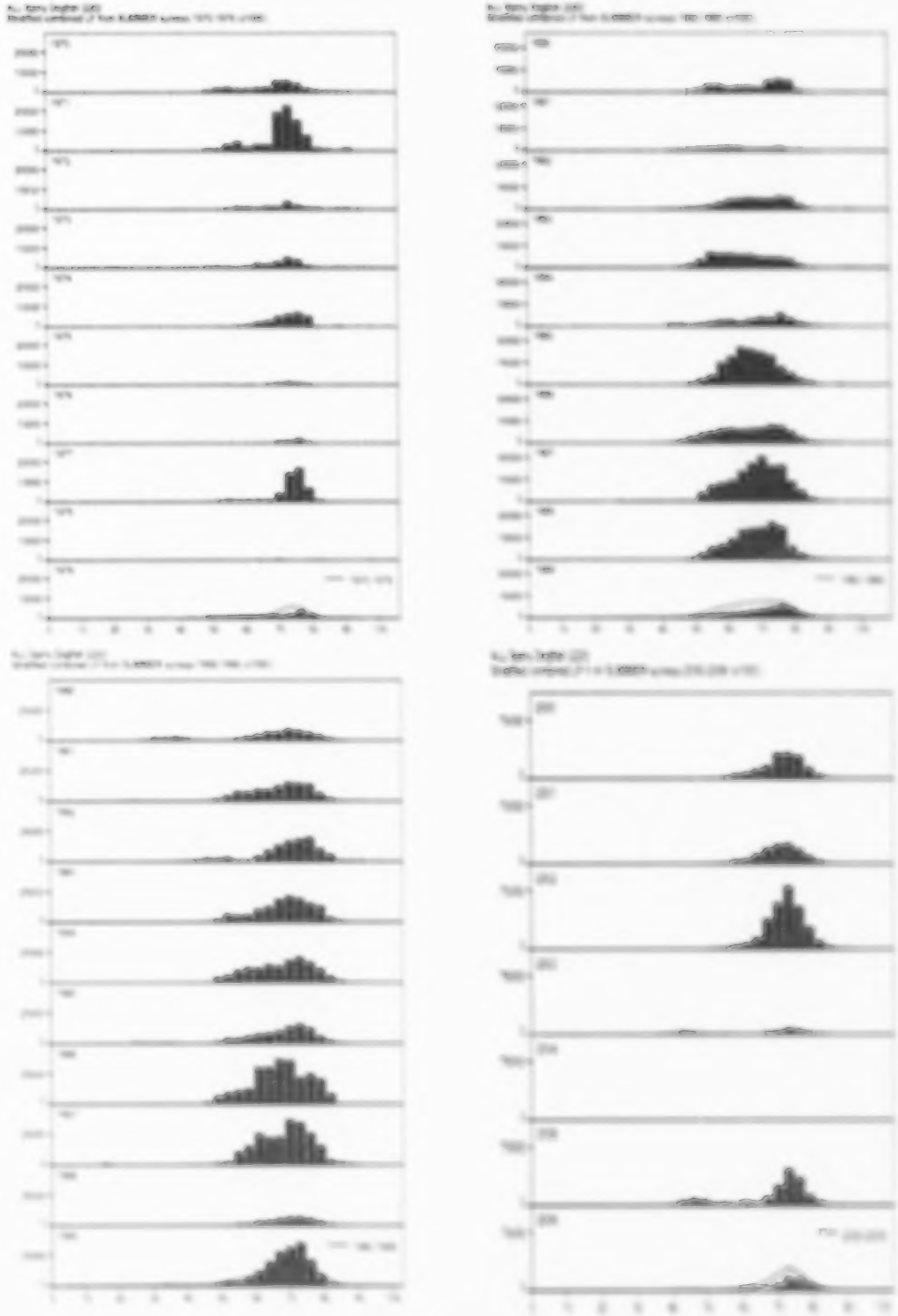


Fig 33. Size composition of spiny dogfish in summer RV surveys of the Scotian Shelf, 1970-2006. Catches by the RV Teleost in 2004 and 2006 are not shown.

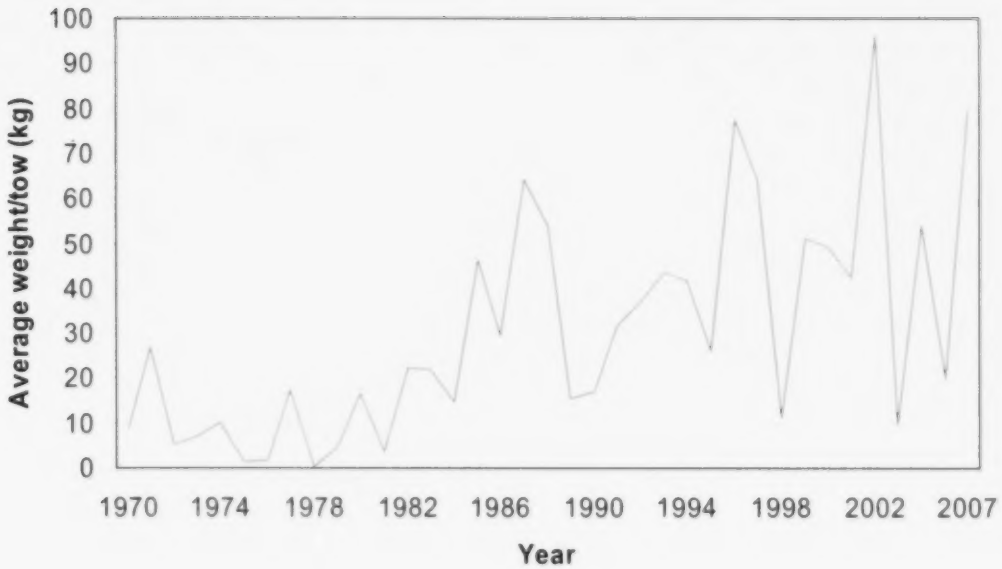


Fig 34. Relative abundance of spiny dogfish in summer RV surveys of the Scotian Shelf, 1970-2007.

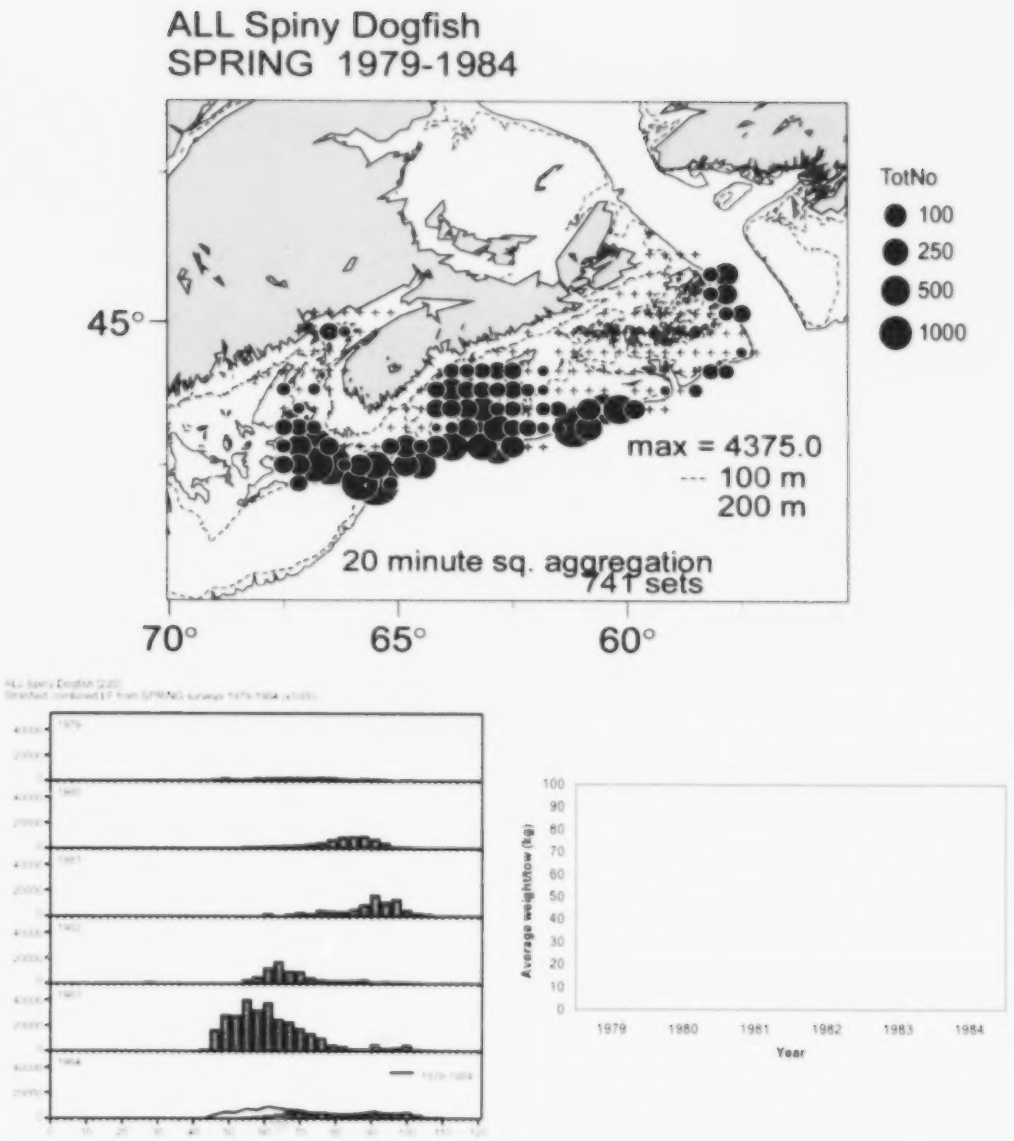


Fig 35. Distribution, size composition and time series of relative abundance of spiny dogfish in spring RV surveys of the Scotian Shelf, 1979-1984.

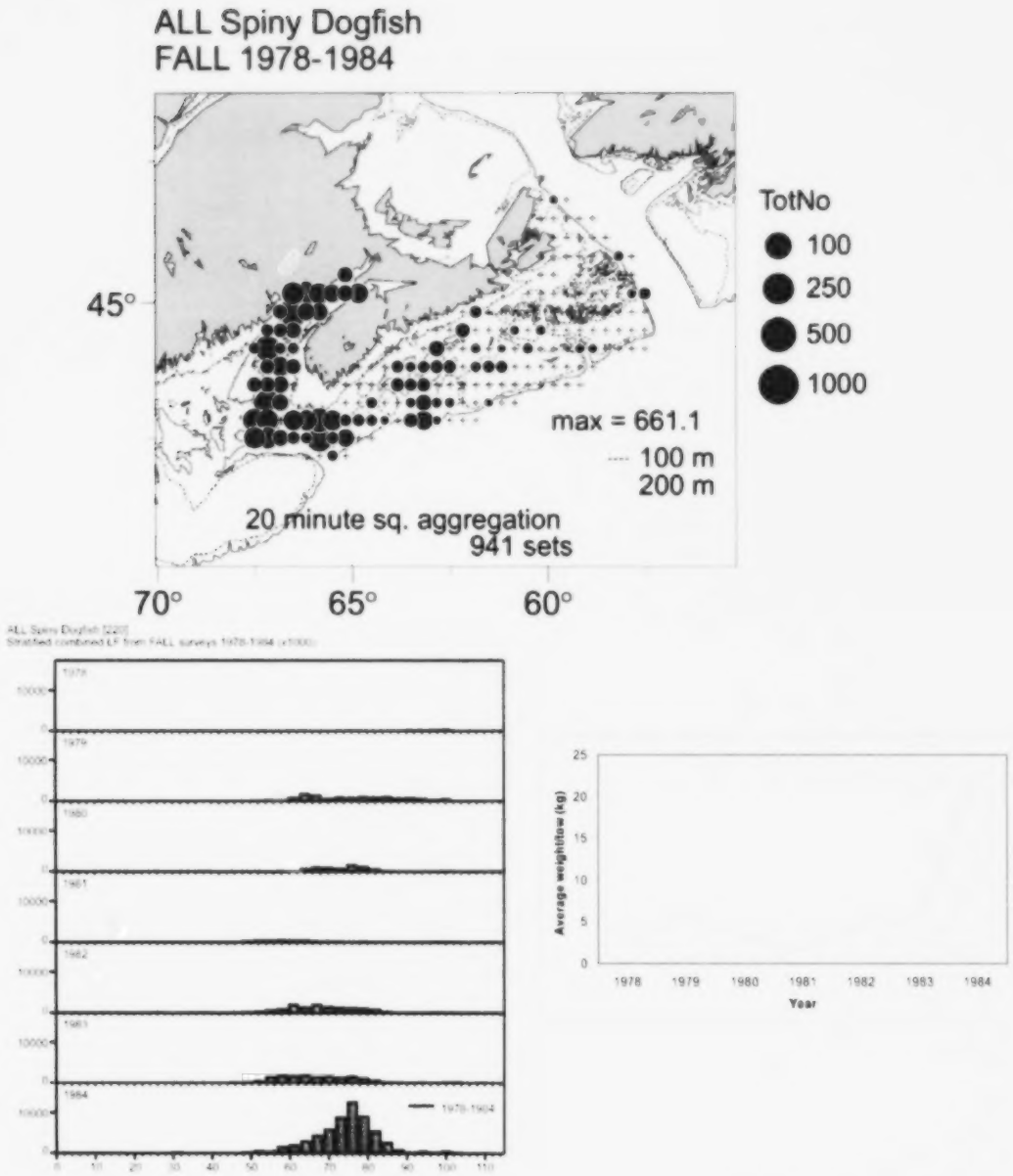


Fig 36. Distribution, size composition and time series of relative abundance of spiny dogfish in fall RV surveys of the Scotian Shelf, 1978-1984.

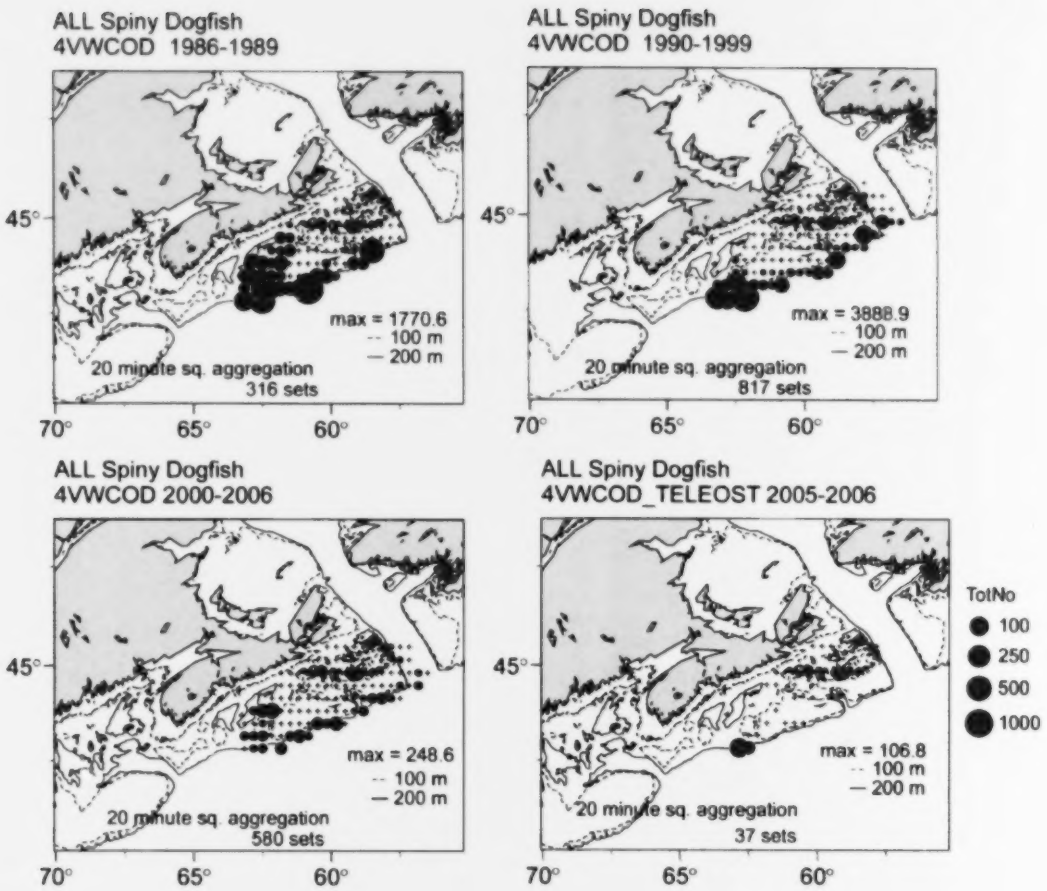


Fig 37. Distribution of spiny dogfish in spring RV surveys of the eastern Scotian Shelf (NAFO 4VW), 1986-2006.

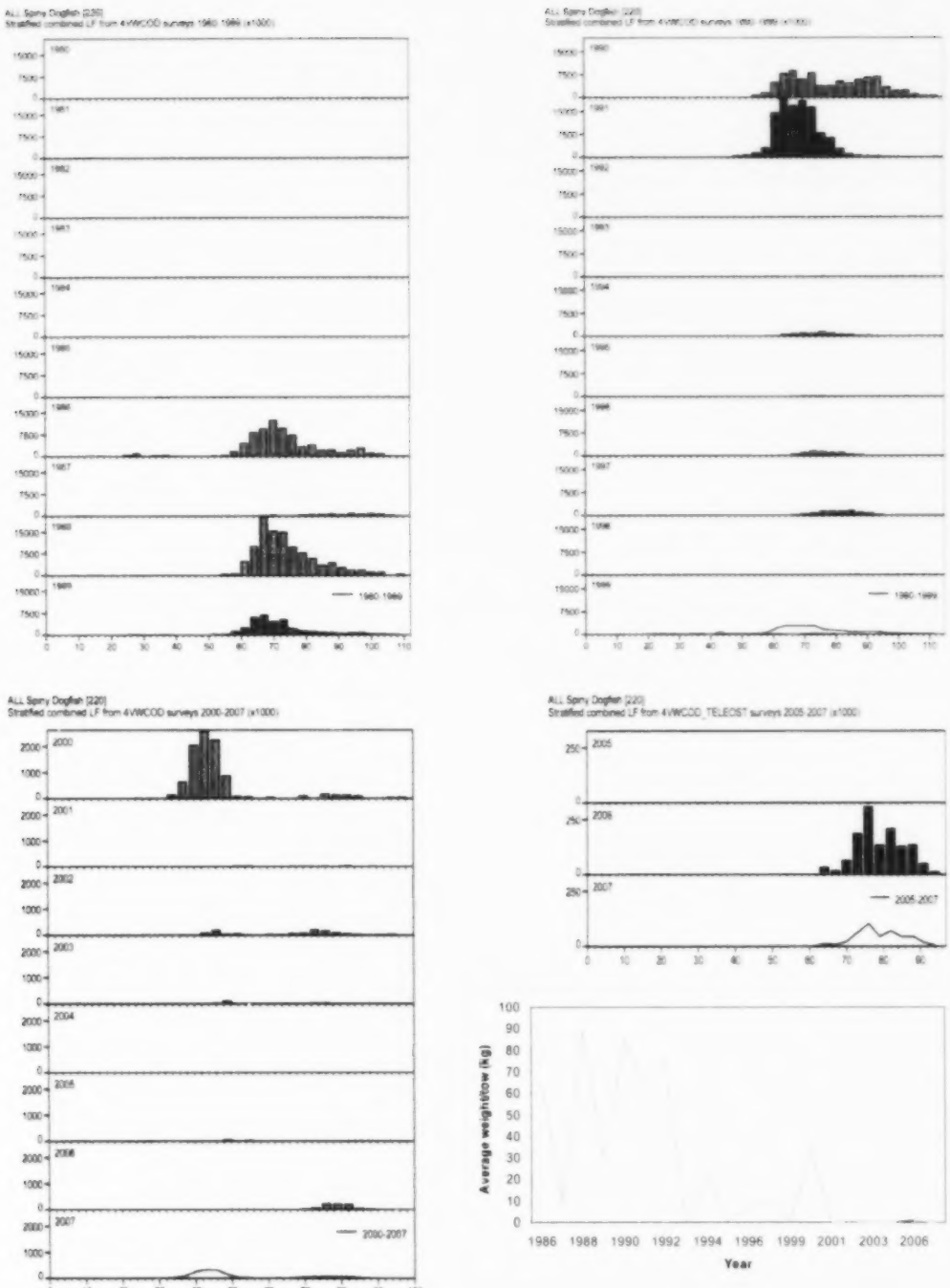


Fig 38. Size composition of spiny dogfish in spring RV surveys of the eastern Scotian Shelf (NAFO 4VW), 1986-2006.

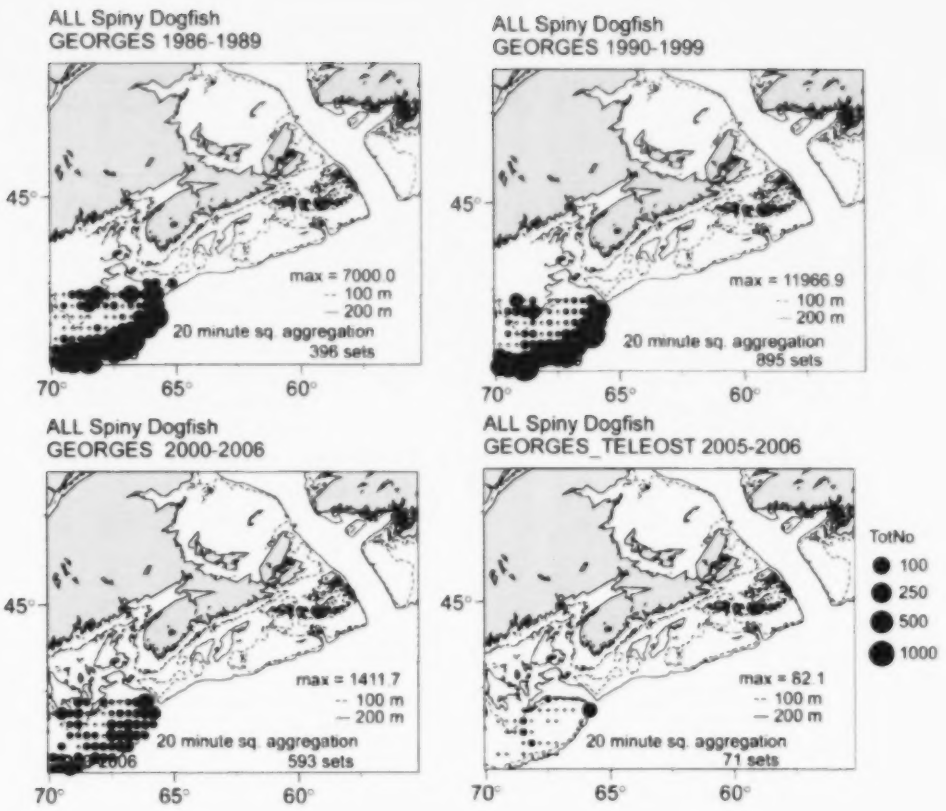


Fig 39. Distribution of spiny dogfish in Feb RV surveys of Georges Bank, 1986-2006.

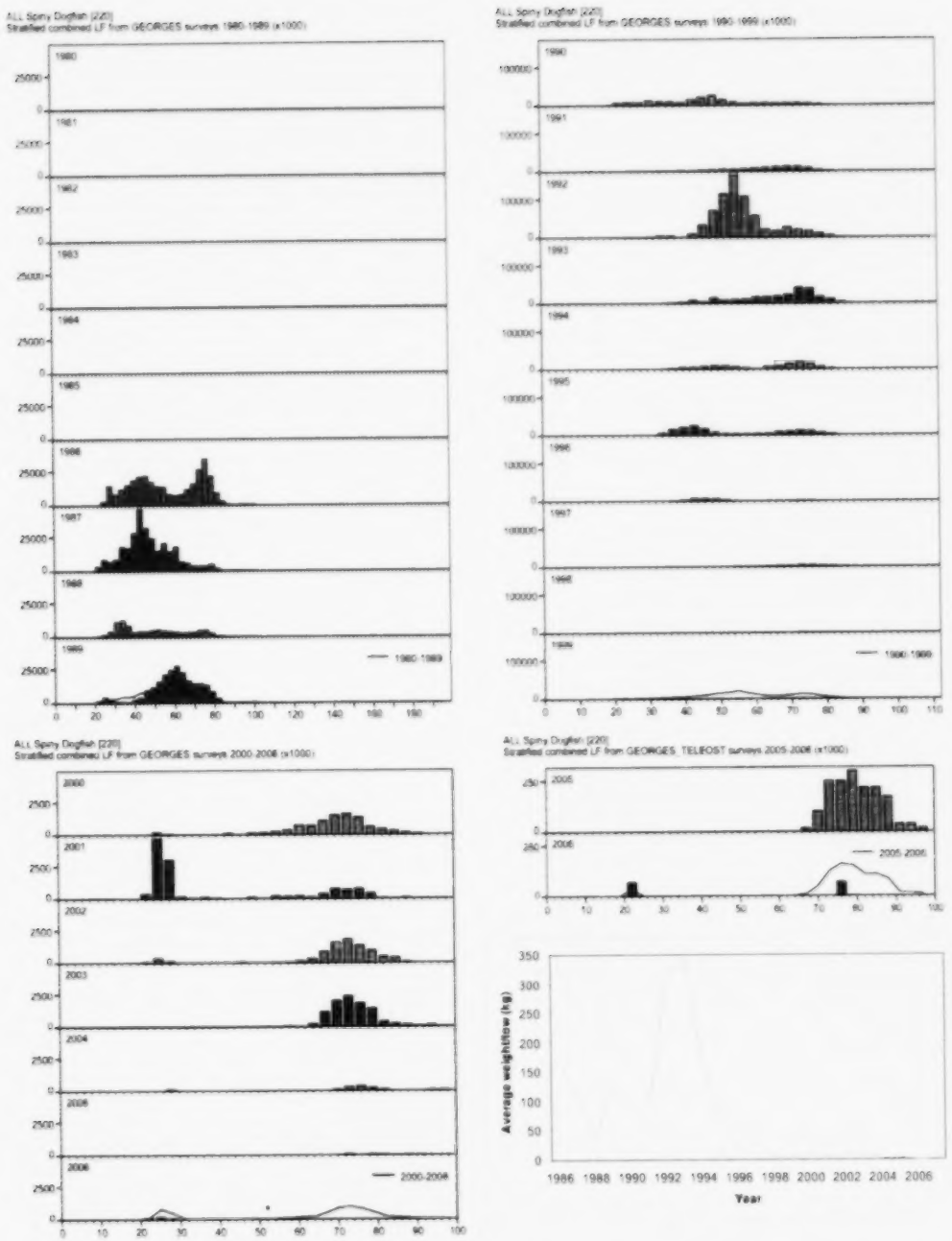
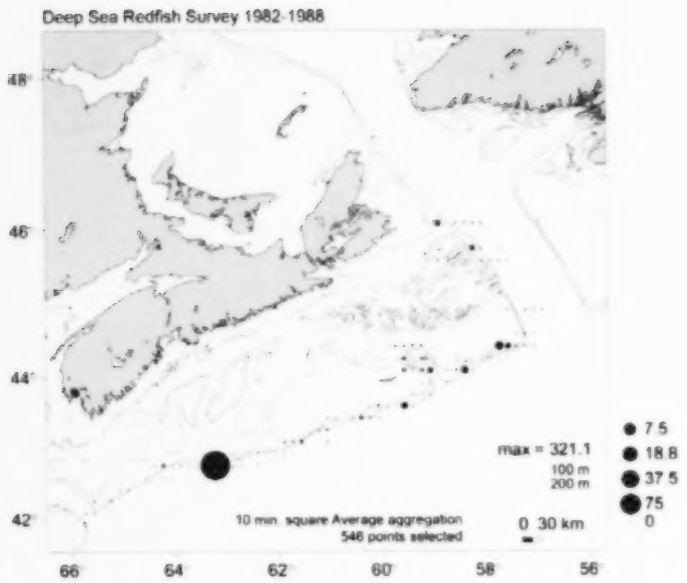


Fig 40. Size composition and relative abundance time series of spiny dogfish in Feb RV surveys of Georges Bank, 1986-2007.



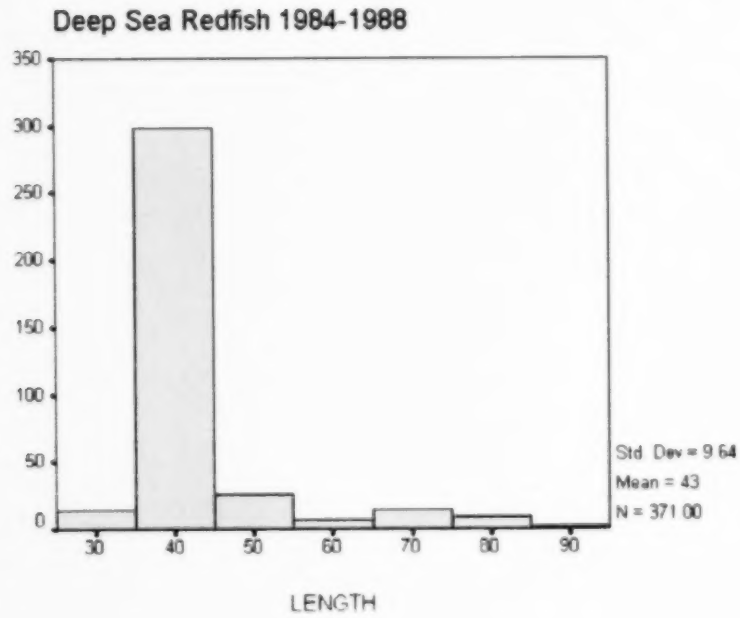


Fig 41. Distribution and size composition of spiny dogfish in Oct-Nov redfish RV surveys of the Scotian Slope, 1982-1988.

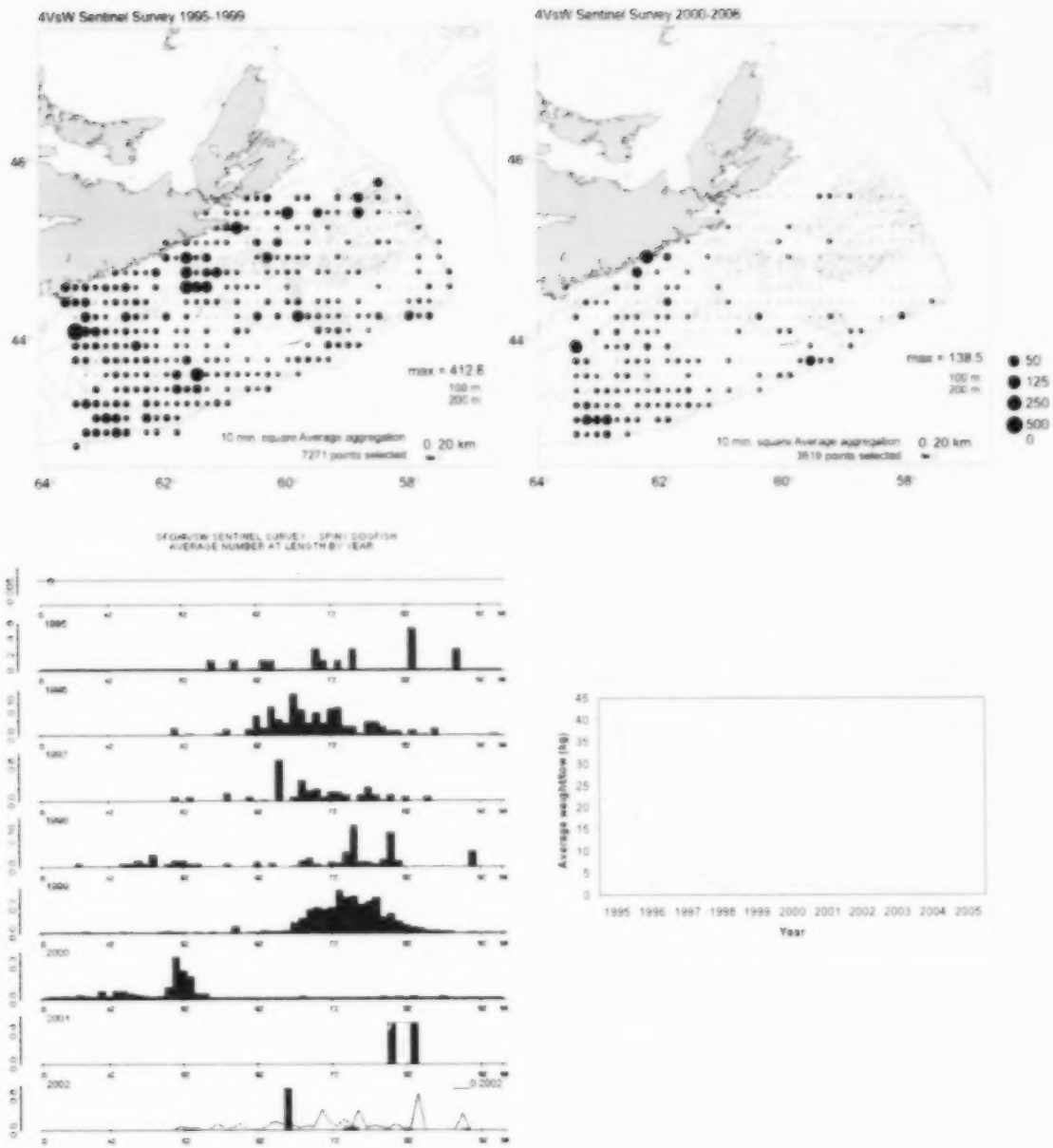


Fig 42. Distribution, size composition and time series of relative abundance of spiny dogfish in Sept-Oct sentinel longline surveys for 4VsW cod on the Scotian Shelf, 1995-2005.

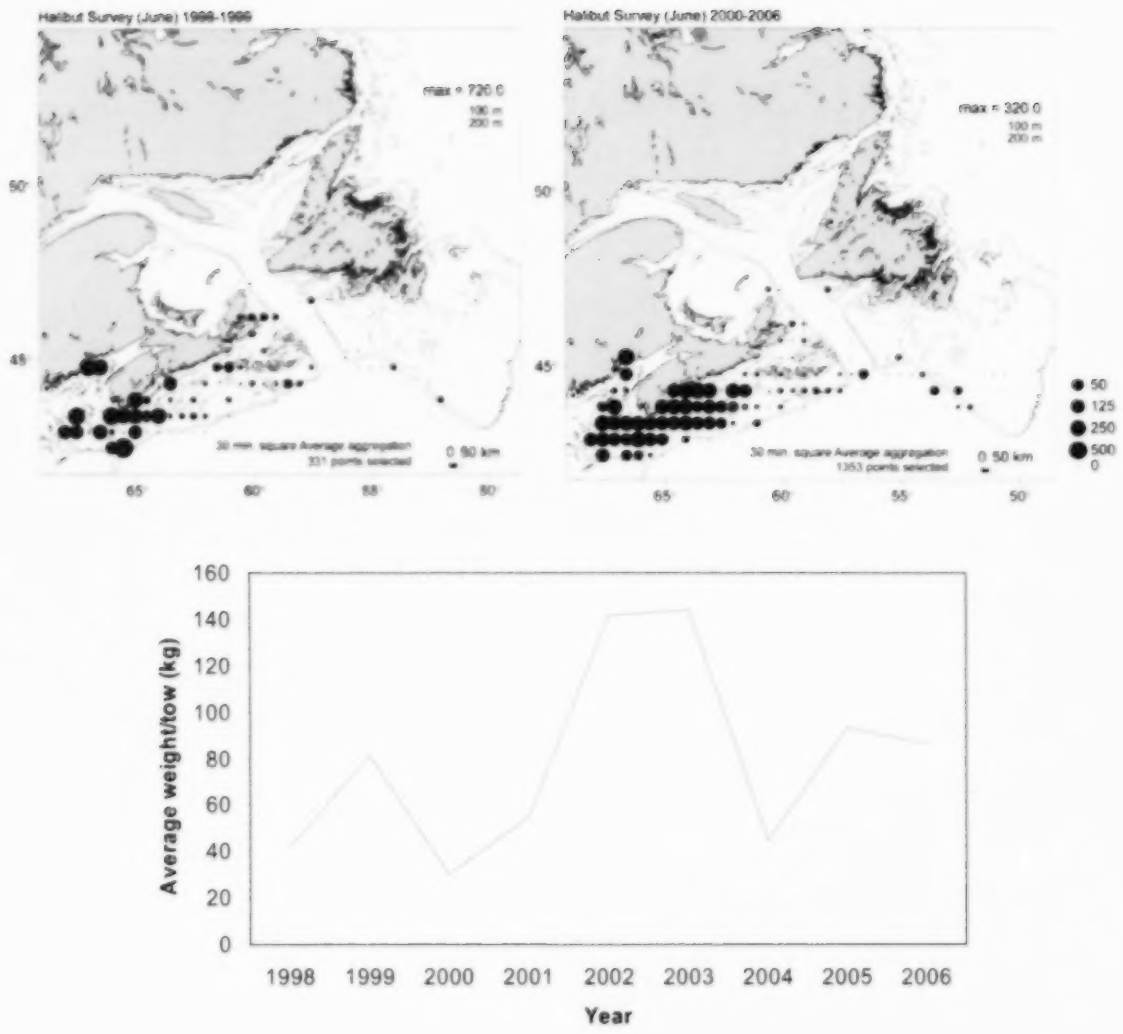


Fig 43. Distribution and time series of relative abundance of spiny dogfish in June longline surveys for halibut on the Scotian Shelf, 1998-2006.

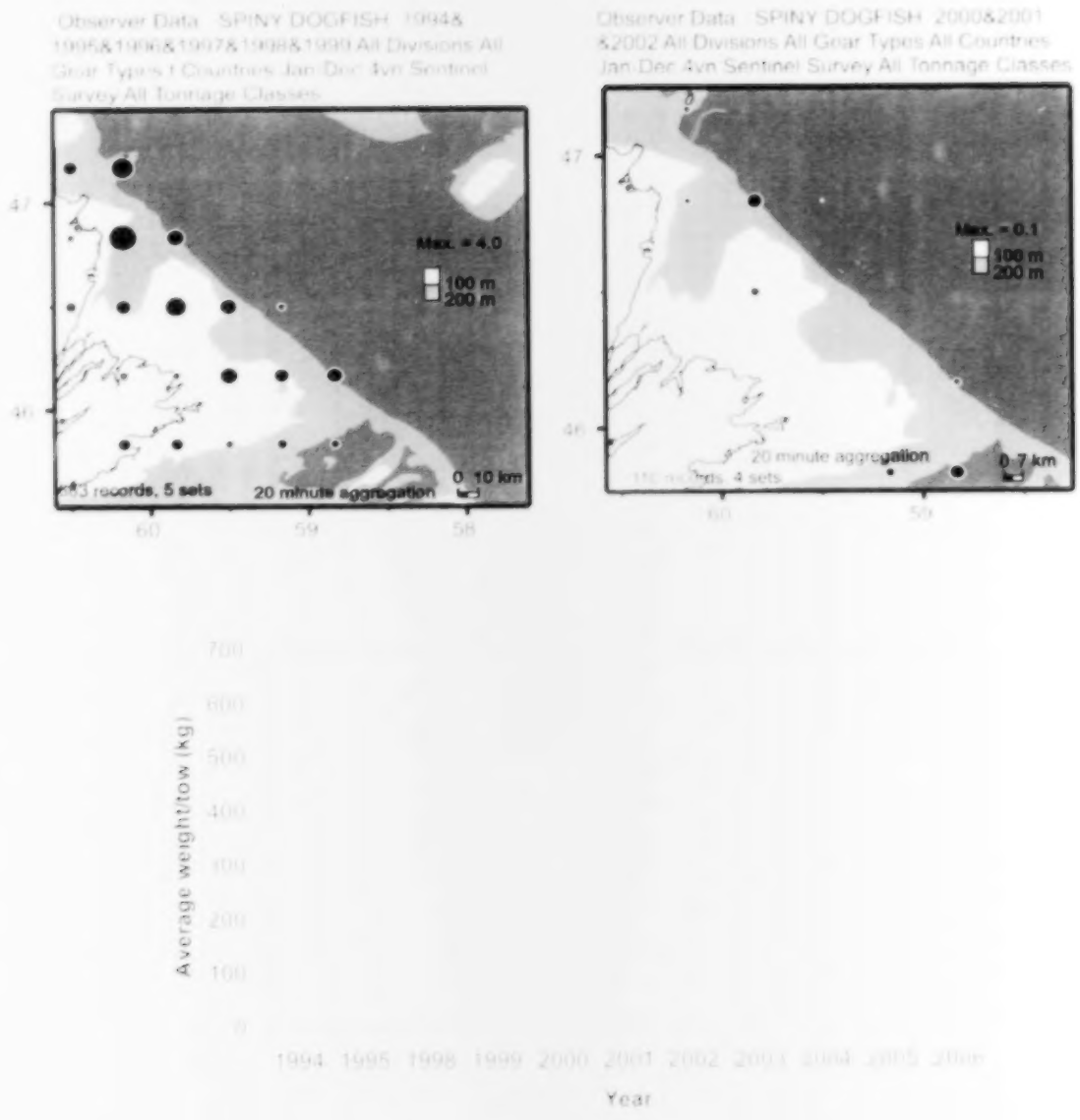


Fig 44 Distribution and time series of relative abundance of spiny dogfish in September longline surveys for 4Vn cod on the Scotian Shelf, 1994-2001.

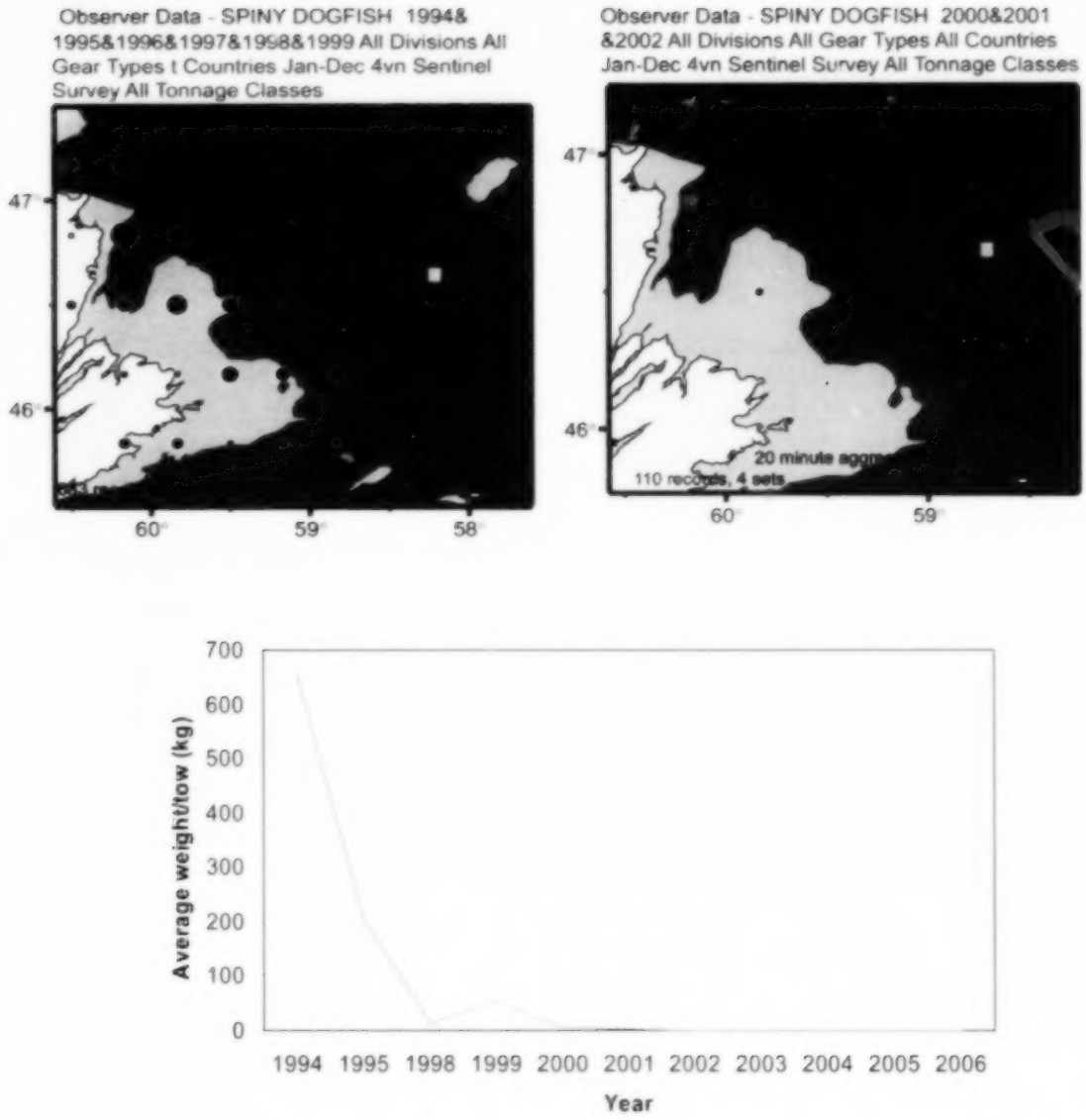


Fig 44. Distribution and time series of relative abundance of spiny dogfish in Sept sentinel longline surveys for 4Vn cod on the Scotian Shelf, 1994-2001.

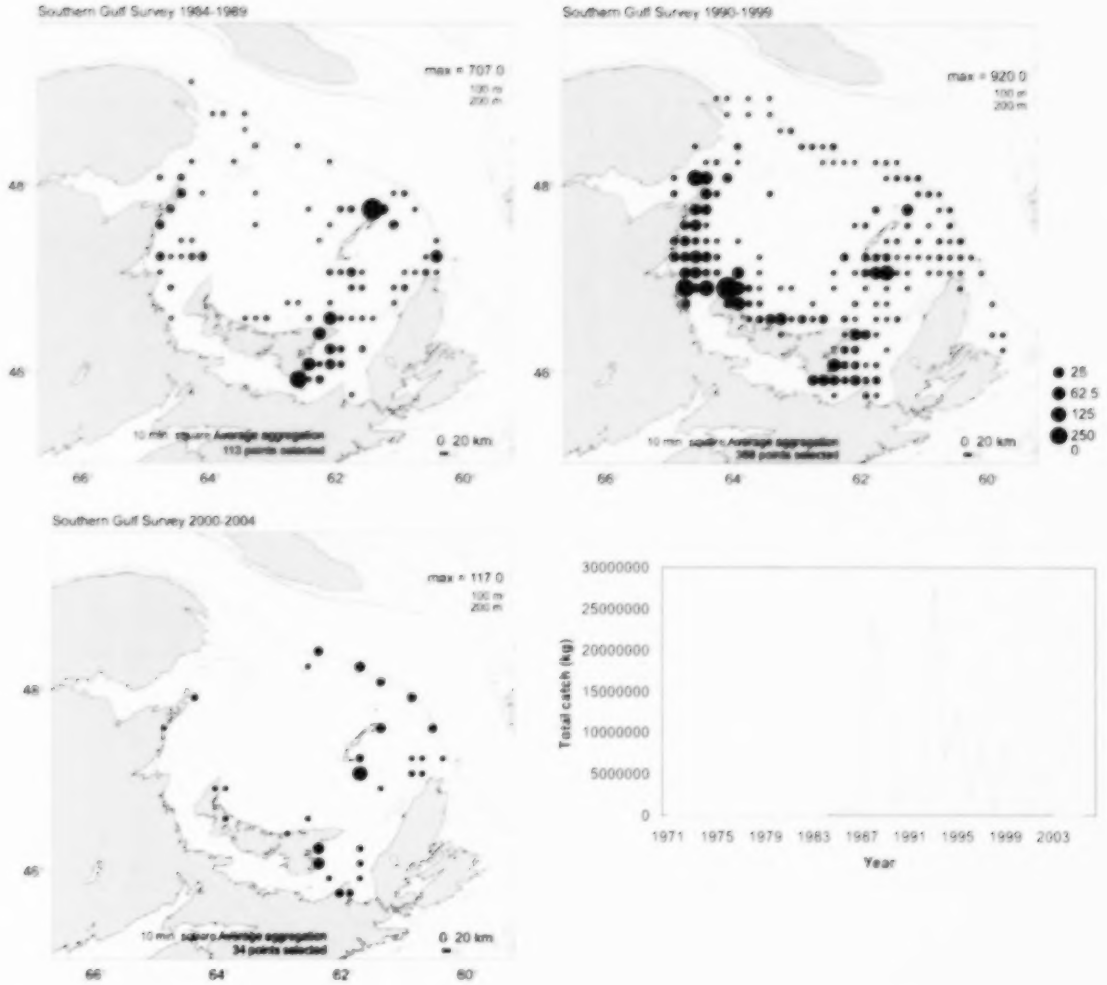
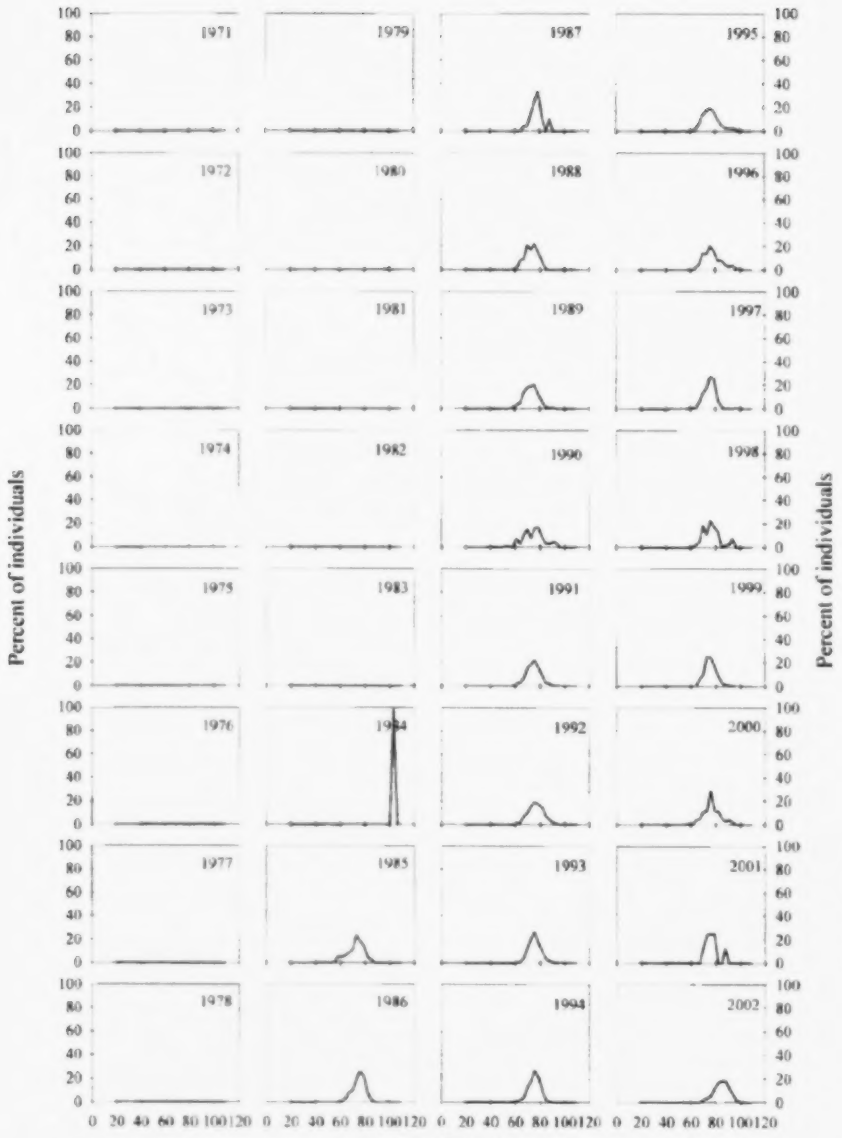


Fig 45. Distribution and time series of relative abundance of spiny dogfish in Sept RV surveys of the southern Gulf of St Lawrence, 1971-2005.



Yearly length frequency distributions for spiny dogfish (*Squalus acanthias*).
(from Benoit *et al*, 2003)

Fig 46a. Size composition of spiny dogfish in Sept RV surveys of the southern Gulf of St Lawrence, 1971-2005.

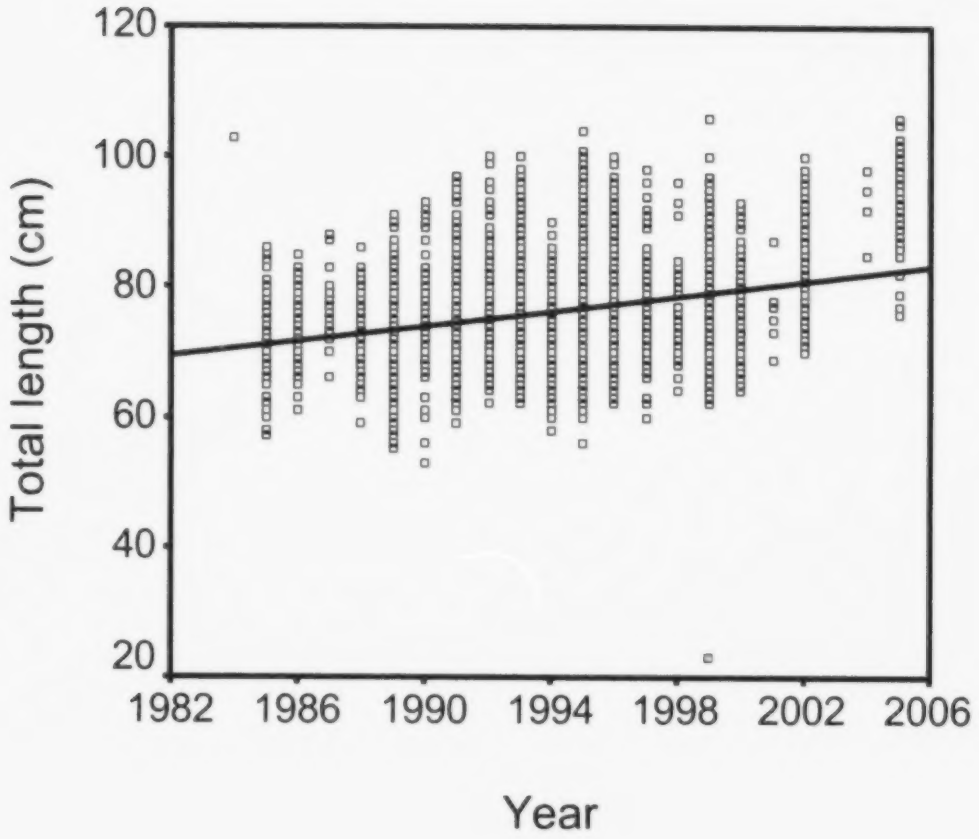


Fig 46b. Change in size composition of spiny dogfish in Sept RV surveys of the southern Gulf of St Lawrence, 1985-2005. The near-absence of new recruits and the gradual increase in mean length are consistent with a 'sink population' – a group of fish that arrived in 1985 and never left.

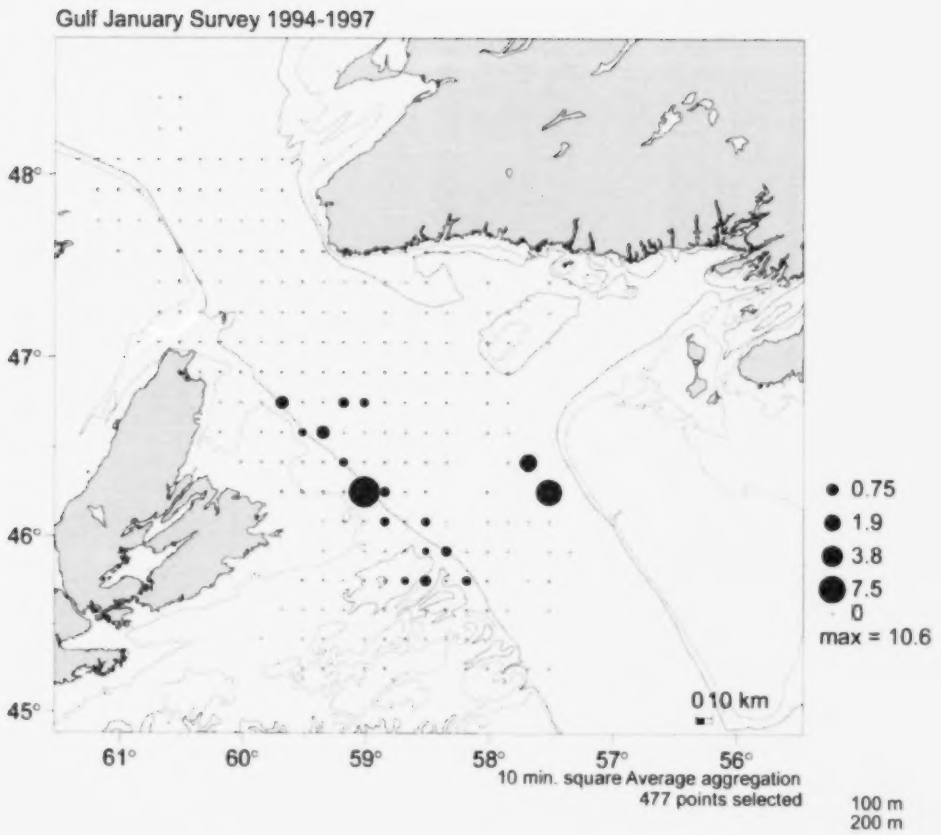


Fig 47. Distribution of spiny dogfish in Jan RV surveys of the southern Gulf of St Lawrence, 1994-1997.

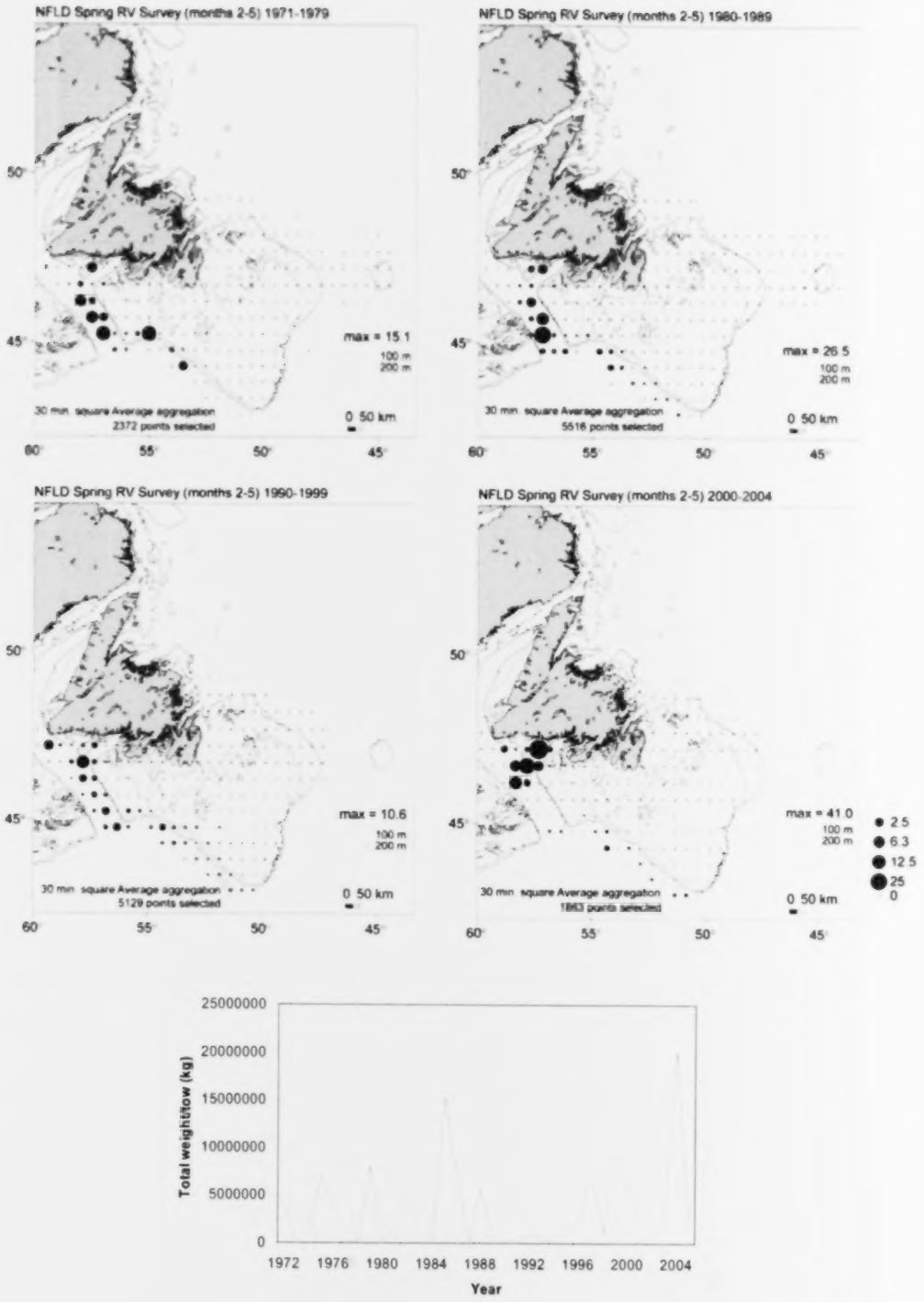


Fig 48. Distribution and time series of relative abundance of spiny dogfish in spring RV surveys of southern Newfoundland, 1972-2005.

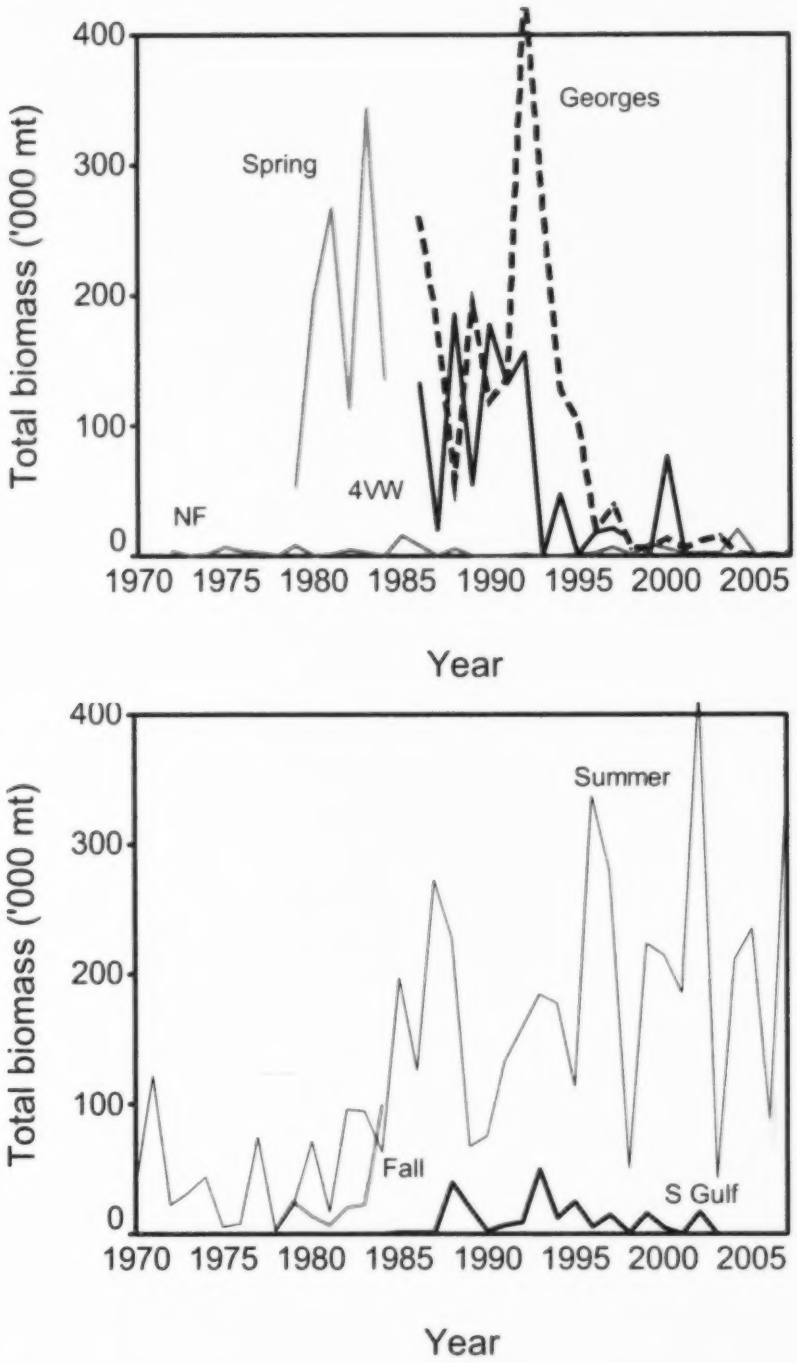


Fig 49. Canadian time series of minimum trawlable biomass of spiny dogfish in spring (top) and summer/fall (bottom) RV surveys of Atlantic Canada, 1970-2007. Spring=Mar RV of Scotian Shelf; 4VW=Mar RV of 4VW; NF=spring RV of southern Newfoundland; Georges=Feb RV of Georges Bank; Summer=July RV of Scotian Shelf; Fall=Nov RV of Scotian Shelf; S Gulf=Sept RV of southern Gulf of St Lawrence.

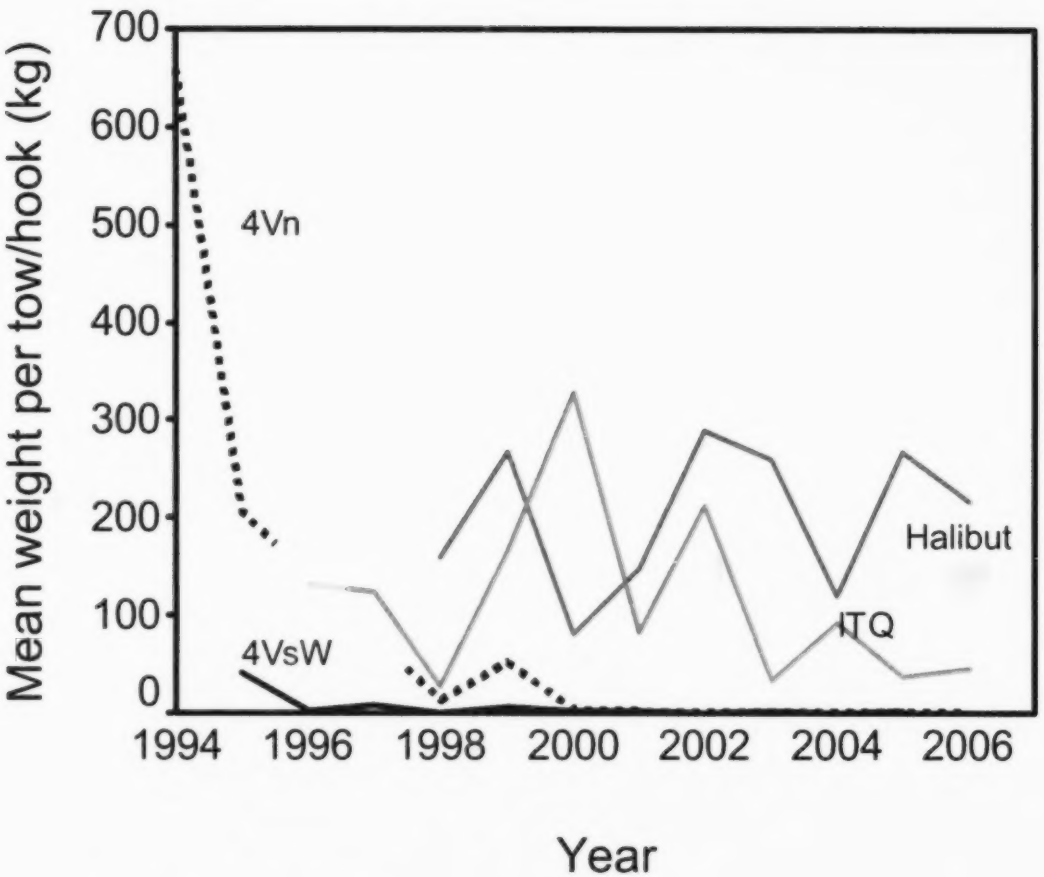


Fig 50. Canadian time series of relative biomass of spiny dogfish in summer/fall sentinel surveys of Atlantic Canada, 1994-2006. 4Vn=Sept 4Vn cod longline survey; 4VsW=Sept/Oct longline survey for 4VsW cod; ITQ=July trawl survey in 4X; Halibut=June longline survey in 4VWX.

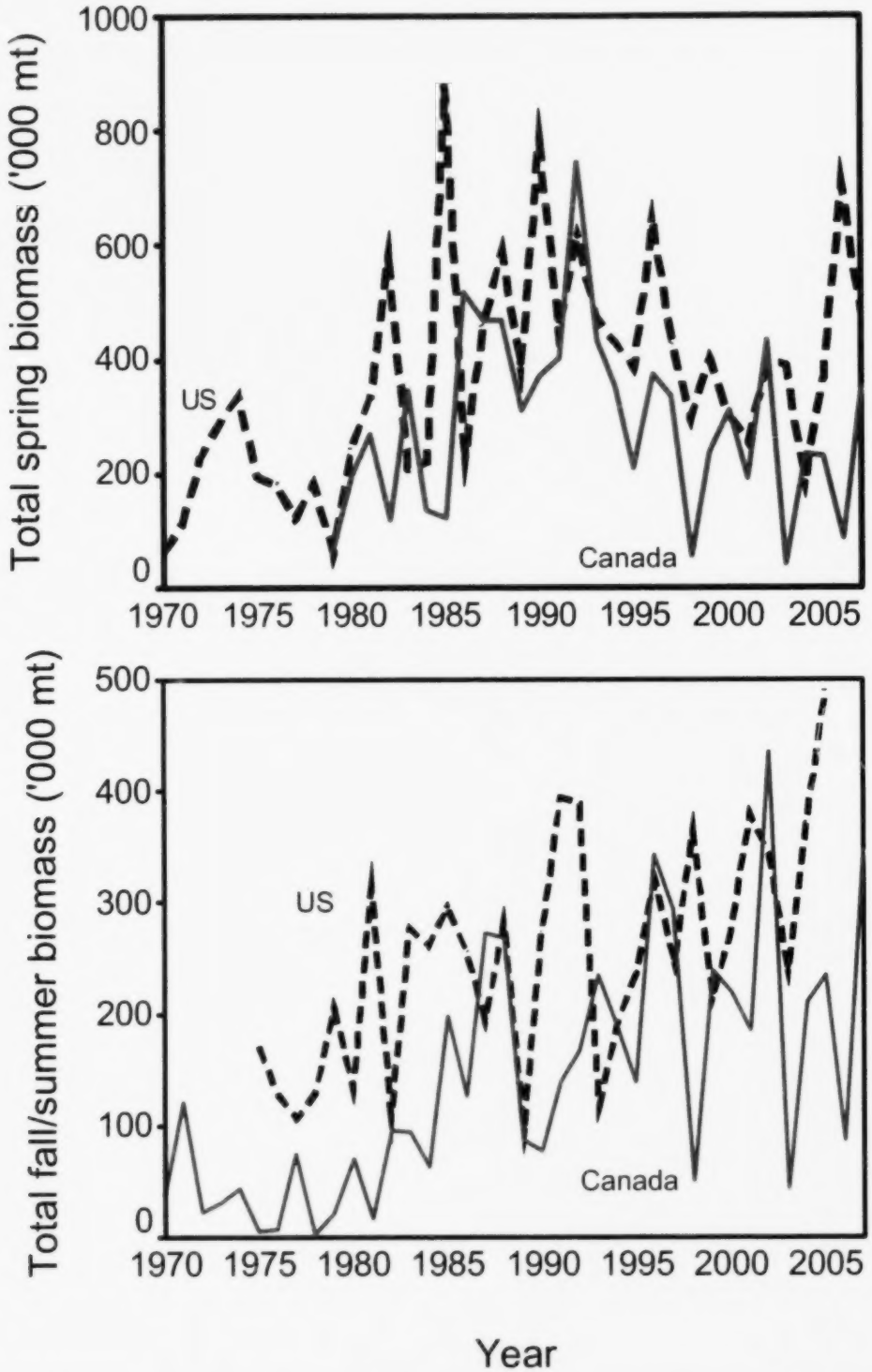


Fig 51. Time series of minimum trawlable biomass of spiny dogfish in spring (top) and summer/fall (bottom) surveys in Atlantic Canada (solid line) compared to the matching U.S. surveys (dashed line), 1970-2007.

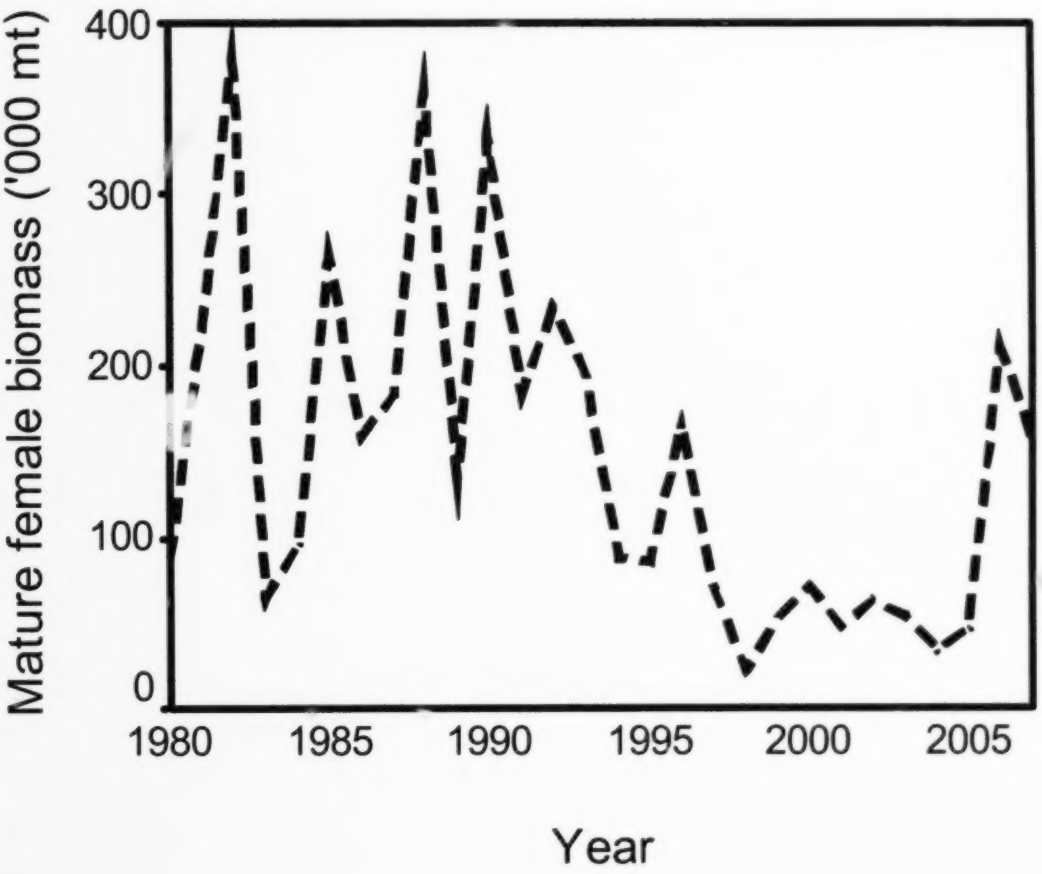


Fig 52. Time series of minimum trawlable biomass of mature female spiny dogfish in the U.S. (NSFC 2006).

APPENDIX 1: POPULATION MODELLING

Population Modeling: Methods

Following the approach used by Gibson and Campana (2006) for porbeagle, we used a forward-projecting age- and sex-structured population dynamics model to estimate abundance-at-age, exploitation rates and fishery reference points for this population. Within this model, the population is projected forward from an equilibrium starting point by adding recruitment and removing catches. Model parameter estimates (e.g. selectivity parameters, catchability coefficients, productivity parameters) are obtained fitting the available datasets using maximum likelihood. Nine Canadian fisheries (1986-2006) as well as the total landings of seven countries from 1960 to 2006 were included in the model. Further details of the data collections are provided in the main text of this report. A spawner-recruit function (a Beverton-Holt function) was parameterized using the asymptotic recruitment (R_{asy}) and slope at the origin (α) and was used to model reproduction.

Population dynamics

Of primary interest is the number of fish in year t, of sex s and of age a, denoted $N_{t,s,a}$. The number of fish in each age class in the next year is given by an exponential decay model. Here, the total mortality rate is given by the sum of the sex and age specific instantaneous natural mortality rate ($M_{s,a}$) and the fishery (g) specific exploitation rate in each year, sex and age class ($u^g_{t,s,a}$).

$$N_{t+1,s,a+1} = N_{t,s,a} e^{-M_{s,a}} \prod_g (1 - u^g_{t,s,a}).$$

The spawner-recruit relationship is expressed in terms of the number of females rather than biomass. Using the letter F to denote the female sex category, the number of female spawners in year t (SSN_t) is a function of $N_{t,F,a}$ and the probability that a female fish of age a is mature at that age ($m_{F,a}$):

$$SSN_t = \sum_a N_{t,F,a} m_{F,a}$$

The life cycle is closed by modeling the number of age-1 fish of each sex in the year t+1 as a function of SSN_t using a Beverton-Holt spawner-recruit (Hilborn and Walters 1992) relationship:

$$N_{t+1,s,1} = \frac{\alpha SSN_t}{1 + \frac{\alpha SSN_t}{R_{asy}}} e^{(\varepsilon_t - \sigma^2/2)} * 0.5$$

Here, α is the slope at the origin, and in the deterministic model is the maximum rate at which female spawners can produce age-1 recruits at low population sizes (Myers et al. 1999); R_{asy} is the asymptotic recruitment level, expressed as the number of age-1 recruits. R_{asy} is the limit approached by R_t as S_t approaches infinity (Beverton-Holt models are often written in terms of the half saturation constant, K, which is related to R_{asy} by: $R_{asy} = \alpha K$). A 1:1 sex ratio at birth is assumed. The model is written so that recruitment can vary around the fitted relationship through

the log of a recruitment deviate for each year (ε_t), in which case a correction for transformation bias based on the standard deviation of the log recruitment deviate (σ) is applied to each deviate, however attempts to estimate deviates to date have not been successful. As written, a lognormal error structure for recruitment (Myers et al. 1995) is assumed. In comparison with the other commonly used 2-parameter SR model, the Ricker model, the Beverton-Holt model has the advantage that R_{asy} can be rescaled and interpreted as an estimate of carrying capacity (Myers et al. 2001), but typically provides estimates of α (and its related reference points) that are higher than those from the Ricker (Myers et al. 1999). Reference points provided by this model are therefore not precautionary with respect to SR model selection.

Commercial fisheries

The influence of commercial fisheries are included in the population dynamics through $u^g_{t,s,a}$. This term consists of two separable components: the gear (or fishery) and sex specific selectivity of the commercial fisheries $s^{g,s}_a$ and the exploitation rate of the fully exploited age class by each gear in each year, u^g_t :

$$u^g_{t,s,a} = s^{g,s}_a u^g_t$$

Selectivity was assumed to follow a double half Gaussian selectivity curve:

$$s^{g,s}_a = \begin{cases} \exp\left(\dfrac{-(a - s^{g,s}_{full})^2}{v^{g,s}_L}\right) & \text{if} \quad a \le s^{g,s}_{full} \\ \exp\left(\dfrac{-(a - s^{g,s}_{full})^2}{v^{g,s}_R}\right) & \text{if} \quad a \le s^{g,s}_{full} \end{cases}$$

where g refers to the commercial fishery. In this model, the age at which fish are fully selected by the fishery is denoted $s^{g,s}_{full}$. The steepness of the decline away from the age at full selectivity is governed by the v parameters for the left and right sides of the curve. Note that selectivity includes both the retention selectivity of the gear as well as contact selectivity (the probability that fish come into contact with the gear). Length-frequency data was not available for all fisheries and some assumptions are made about the selectivity of the fisheries. All foreign landings are assumed to have been removed by trawling with a selectivity equal to the more recent summer research vessel (RV) trawl survey. The selectivity of the trawl fisheries is also assumed to match the summer RV survey. Selectivity is estimated for the gillnet and the directed longline/handline fisheries as length-frequency data is available for these fisheries. Nearly all recent landings come from these fisheries.

We assume the catch is taken during a short time period half way through the year, an approximation attributed to Pope (Quinn & Deriso 1999) and that the total catch (biomass) in each year by each fishery (C_t^g) is known without error. The exploitation rate (proportion of the vulnerable biomass removed) in each fishery in each year is then:

$$u_t^g = \frac{C_t^g}{N_{1,s,a} s_a^{g,s} w_{s,a} \sum_{s,a} e^{-0.5 M_{s,a}}}$$

where $w_{s,a}$ is the sex specific weights at age.

Initial conditions

Two approaches were used to estimate the population size and age structure at the start of the time period (1960). The first approach involved estimating two parameters: $N_{1960,1}$ and Z_{start}. The first parameter is the number of age-1 dogfish in 1960 and the second is used to estimate the abundance of dogfish in other age classes in 1960 using an exponential decay function. The second approach adopted for the model runs presented here was to estimate $N_{1960,1}$ and to assume an unfished equilibrium age structure (reported landings in the early 1960's were quite low).

Predictions from the model

Parameter estimates are obtained from the model by minimizing the discrepancies between the observed data and predictions from the model. The model is fit to research survey catches, survey proportions-at-age and the proportions-at-age in some of the commercial fisheries. Constants used in the model are listed in Table A1.1. Thus we want to obtain predictions of the survey catches (I_t^i) where the superscript i is used to index the survey, and to obtain the predicted length composition of the catch in the fisheries and the length composition of the survey catches.

Under the assumption that the survey catch is proportional to abundance, the predicted catch is given by:

$$I_t^i = q^i \sum_{s,a} e^{-\gamma(M_{s,a} + F_{1,s,a})} s_{s,a}^i N_{1,s,a}$$

Here γ is the proportion of the mortality that occurs prior to the survey, set equal to 0.25 for surveys occurring in the spring, 0.5 for surveys occurring in the summer and 0.75 for surveys occurring in the fall. None of the surveys cover the full range of the population, so the catchability of each survey, q^i, included both the catchability of the gear as well as the proportion of the population in the area covered by the survey. Thus, with the exception of the summer groundfish survey which is broken into two parts to reflect a vessel change, an assumption exists that the distribution of dogfish has not changed systematically during the period covered by the surveys.

The sex-specific predicted length compositions in the catches, $P_{t,l}^{g,s}$, are a function of the population age composition, the selectivity curves and the distributions of length at age:

$$P_{t,l}^{g,s} = \frac{\sum_a s_a^{g,s} f_{l|a}^s N_{t,s,a}}{\sum_a s_a^{g,s} \sum_l f_{l|a}^s N_{t,s,a}}.$$

The sex-specific length proportions at age ($f_{l|a}^s$) is given by:

$$f_{l|a}^s(l_a^s, \sigma_a^s) = \frac{\delta}{\sqrt{2\pi}\sigma_a^s} \exp\left[\frac{-\left(x_i^s - l_a^s\right)^2}{2\left(\sigma_a^s\right)^2}\right]$$

where δ is the size of the length increment (3 cm in this analysis). We used a von Bertalanffy growth model to model the relationship between length and age (Figure A1.1), and examined the relationship between the standard deviation of length and age to determine their relationship. No simple relationship was evident (Figure A1.2), so σ_a^s was assumed constant over ages with separate values for each sex. Constants are provided in Table A1.1.

The predicted length compositions in the surveys, $P_{t,l}^{i,s}$ were found similarly.

Likelihood equations

The model was fit to the data by minimizing an objective function (*O.F.V.*) that is the sum of the negative log likelihoods for the survey series (ℓ_{SURVEY}), the length compositions in the catches ($\ell_{catch-comp}$) and the length compositions of the surveys ($\ell_{survey-comp}$). We used lognormal error structures for the total survey catch time series and a robust normal error structure for the proportions at length in the catch and surveys. For each survey, the log-likelihood for the total catch is given by:

$$\ell^i_{survey} = -\sum_1^n \ln \sigma^i - \frac{1}{2}\log 2\pi - \sum_t \frac{(\ln \tilde{I}_t^i - \ln I_t^i)^2}{2(\sigma^i)^2},$$

where n is the number of observations in the series, σ^i is the standard deviation of a normal distribution prior to exponentiation and $\tilde{I}^i$ is the observed survey index value in year t. We used a constant value of 0.3 for all σ^i in this analysis.

For a given gear and sex category, the robust normal log-likelihood for proportions at length in the catch is:

$$\ell^{g,s}_{length-comp.} = 0.5\sum_{t=1}^{Y}\sum_{l=1}^{A}\log(2\pi(\varsigma_{t,l}^{s,g} + 0.1/A_l)) + \sum_{t=1}^{nyears} A_l \log(\tau_t^{s,g})$$
$$- \sum_{t=1}^{Y}\sum_{l=1}^{A}\log\left[\exp\left\{\frac{-\left(\widetilde{P}_{t,l}^{s,g} - P_{t,l}^{s,g}\right)^2}{2\left(\varsigma_{t,l}^{s,g} + 0.1/A_l\right)\tau_t^{s,g}}\right\} + 0.01\right]$$

where Y is the number ofwith observed proportions at length, A is the number of length categories, $\tau_t^{s,g}$ is the sample size and $\varsigma_{t,l}^{s,g}$ is the variance (Fournier et al. 1990). Sample sizes were arbitrarily set at 1,000 for all years so that the catch-at-length data for all years was weighted equally, and the variance used was that of the predicted proportions (Fournier et al. 1990):

$$\varsigma_{t,l}^{s,g} = P_{t,l}^{s,g}(1 - P_{t,l}^{s,g}).$$

We used a length-frequency distribution of the sexes combined for some years (see the Data section) with appropriate modifications to the above equations.

Two penalty functions are used to constrain the model during estimation. Because the catch-at-age is subtracted from the numbers-at-age, a small penalty is added to the objective function to keep the numbers-at-age positive. A second penalty function is used to constrain the exploitation rate to be less than 50%.

The final objective function is then:

$$O.F.V. = -\left(\sum_{i}\ell^{i} + \sum_{g,s}\ell^{g,s}_{catch-comp.} + \sum_{g,s}\ell^{g,s}_{survey-comp.} + penalties\right)$$

We programmed this model using AD Model Builder (Fournier 1996). AD Model builder uses the C++ auto-differentiation library for rapid fitting of complex non-linear models, has Bayesian and profile likelihood capabilities, and is designed specifically for fitting these types of models.

The production model and reference points

We modelled the population dynamics using two equations: a spawner-recruit relationship that expresses recruitment as a density dependent function of spawner abundance, and the replacement line, the slope of which is the inverse of the rate at which recruits produce replacement spawners. Here, an implicit assumption is made that all density-dependent processes occur between spawning and recruitment. The production model also includes a third component: a yield per recruit relationship. Recent Canadian landings are highest in the directed longline/handline fishery. We therefore used the selectivity curves for this fishery when estimating reference points. All results are therefore specific to that fishery. Results would vary if other selectivity curves were assumed.

The SR model was discussed in the previous section. We modelled the rate at which recruits produce spawners (the inverse of the slope of the replacement line) by calculating the number of

spawners per recruit (SPR_F) as a function of fishing mortality (Shepherd 1982, Mace and Sissenwine 1993, Mace 1994):

$$SPR_F = 0.5\sum_{1}^{a_{max}}\left[m_a e^{-\sum_{1}^{a-1}(M_{F,a-1}+F^g_{F,a-1})} \right] ,$$

where $F^g_{F,a}$ is the age and gear specific fishing mortality rate for females. Again, these calculations are specific to the selectivity assumed in the calculation.

The yield per recruit for a given F (YPR_F) is found similarly:

$$YPR_F = \sum_{s}\sum_{1}^{a_{max}} e^{-\left(0.5M_{s,a}+\sum_{1}^{a-1}(M_{s,a-1}+F^g_{s,a-1})\right)}\left(1-F^g_{s,a}\right)w_{s,a} .$$

For a given value of F, the spawning biomass produced by the number of recruits in year t is $SSN = SPR_F \cdot R_t$. Equilibrium spawning biomasses and recruitment levels (denoted with asterisks) were found by solving this equation for R_t, and substituting the result into the spawner-recruit model (Quinn and Deriso 1999):

$$\frac{SSN^*}{SPR_F} = \frac{\alpha SSN^*}{1+\frac{\alpha SSN^*}{R_{asy}}} .$$

The equilibrium spawning biomass (SSB^*) is then:

$$SSN^* = \frac{(\alpha SPR_F - 1)R_{asy}}{\alpha} ,$$

and the equilibrium number of recruits (R^*) is found by substituting the SSN^* in the spawner-recruit model:

$$R^* = \frac{\alpha SSN^*}{1+\frac{\alpha SSN^*}{R_{asy}}} .$$

The equilibrium catch (C^*) is R^* multiplied by the yield per recruit for the given value of F:

$$C^* = R^* \cdot YPR_F .$$

Reference points from the spawning biomass per recruit and yield per recruit analyses were found using a grid search across a set of F's {0 to 4.0; increment of 0.0025}. We calculated YPR_F and SPR_F for each value of F, and reference points were then estimated by selected the fishing mortality rate corresponding to the appropriate reference point criterion. The $SPR_{x\%}$ reference points were found by selecting the fishing mortality rate where the SPR_F was x% that of $SPR_{F=0}$.

We estimated five reference points from the production model. The equilibium spawning biomass in the absence of fishing, SSN_{eq}, was estimated directly from the production model. A spawning biomass of 20% SSN_{eq} is sometimes used as a minimum threshold population size (Beddington and Cooke 1983, Goodyear 1993). $SSN_{20\%}$ was calculated as 20% the equilibrium female spawner abundance in the absence of fishing:

$$SSN_{20\%} = 0.2\frac{(\alpha SPR_{F=0} - 1)R_{asy}}{\alpha}$$

The grid searches were used to find the fishing mortality rate that produces maximum sustainable yield (F_{msy}), the corresponding spawner biomass that produces maximum sustainable yield (SSN_{msy}) and the fishing mortality rate that drives the population to extinction (F_{col}). We estimated F_{msy} by calculating C^* for each value of F, and selecting the value where C^* was maximized. SSB_{msy} was the value of S^* corresponding to this fishing mortality rate. The equilibrium fishing mortality rate at which the population goes extinct, F_{col}, is determined by the slope of the SR relationship at the origin α, and is the value of F where $1/SPR_{F=0} = \alpha$.

Population Modelling: Data

Data used in the model are shown in Figures A1.3 to A1.13. The survey data series (Figure A1.3), show different trends. The cod4VW RV survey, Georges RV, and sentinel 4VsW longline survey show declining trends in the index value. The summer RV survey is split into two indices to reflect a gear change in 1982. Taken together, these surveys show an increasing trend, whereas if treated separately, they indicate a high but stable population in recent years. The total landings (Figure A1.3) were primarily foreign from the mid-1960's to the late 1970's whereas the bulk of the recent landings are domestic. Most of the recent landings are in the directed longline/handline and gillnet fisheries (Figure A1.4).

Length-frequency data for the commercial fisheries that were used in the model are: the 4X longline/handline fishery from 1997 to 2006 (Figure A1.5), the 4W gillnet fishery from 2003 to 2006 (Figure A1.6) and the 4X gillnet fishery (Figure A1.7). Trends are not obvious in these data although the data are variable from year-to-year and a marked outlier is present in the 4X gillnet data for males.

Six length frequency data series were used from the surveys (Figures A1.8 to A1.13). The summer survey proportions-at-length (Figure A1.8) show decreasing proportions of smaller dogfish from the mid-1990's onwards, although some recent surveys have captured proportionally higher numbers of smaller dogfish. The 4VsW sentinel longline survey (Figure A1.9) and the 4VW cod survey (Figure A1.10) have highly variable proportions-at-length. The Georges RV survey (Figure A1.12) also shows a shift to greater proportions of larger dogfish with some exceptions since 2000.

Population Modeling: Results and Discussion

We took a stepwise approach to building this population model. We first included only the commercial data and summer RV survey data, and then added the other data discussed above. More data could be added to the model, although addressing some of the issues identified herein should be a first step prior to expanding the model (see discussion).

When examining the model results, the reader should be aware of some of the model behaviours. The first is that, in its present form, the model has a tendency to converge at local minima. Although the summer RV survey index suggests an increasing population size, the summer proportions-at-length and some other survey data are indicative of a declining population size. One solution to this issue is for the model to drift to very high constant population size estimates (hundreds of billions) and to assume all trends are noise. In these runs exploitation rate estimates are extremely low, and if estimated in the model, the estimate of α tends to a low value so that the population size does not change much from 1960 to present. This problem was more common when all data were included. A second behaviour is that in nearly all formulations that were evaluated (most of which are not presented), if R_{asy} is estimated within the model, the estimate is equal to the upper bound, even at high values for α. In the runs presented, R_{asy} is fixed arbitrarily at 50 billion age-1 recruits. As a result, very little density dependence occurs within the model, and for this reason fishery reference points such as B_0, F_{msy}, B_{msy} have little meaning. They are not presented in the results for this reason. When convergence occurs at more realistic abundance levels (and at a lower OFV), the estimates of α exceed the maximum fecundity of dogfish by a factor of about three.

In an attempt to avoid the above issues, we fit models with α set at constant values ranging form 1.25 to 4. Given an average litter size of 6 pups every 2 years, an alpha of 1.25 would correspond to a survival to age-1 of roughly 40% and, assuming the survival rates and maturity schedule herein, corresponds to a lifetime reproductive rate of 1.04. A value of 4 slightly exceeds the average annual fecundity (but not that expected from larger females) and corresponds to a lifetime reproductive rate of 3.34. These scenarios are intended to bracket what might be plausible reproductive rates for dogfish.

Six model runs are presented in this paper to illustrate the above issues: three models fit only to the summer RV and commercial proportions-at-length data with values of α set at 1.25, 2, and 4, and three models fit to all the data with α set at 2 (two runs with different starting vales for N_1) and at 4. Parameter estimates are provided for all six models, but the diagnostic plots are provided only for the model fit to all the data with α set at 2 and a low starting value for N_1. For the reasons above, as well as some of the residual issues discussed below, none of the results presented should be interpreted as being a good approximation of the status of dogfish.

Model parameter estimates for the summer RV survey only fits (Models 1 to 3; α = 1.25, 2 and 4 respectively) are provided in Table A1.2. Parameter estimates for the model runs fitted to all the data: two with α =2 (two runs with different starting vales for N_1) and one with α =4 are provided in Table A1.3. In Model 4, the starting value for N_1= 70 million fish, and in Model 5 it is set at 1.7 million fish, and the models converge at different values with different trajectories. Model 6 has α =4.

Both abundance estimates (Tables A1.4 and A1.5) and abundance trends (Figure A1.14) differ markedly among models. Models 1 and 5 show a declining trend in spawner abundance, models 2 and 4 show no trend, whereas 3 and 6 show a strongly increasing trend. This pattern is mostly explained by the assumed productivity in each run.

Selectivity parameters are mostly similar among the models (Table A1.2 and Table A1.3), and indicate a relatively narrow selectivity curve for all gear except the new summer survey and spring survey for females (Model 5 example in Figure A1.15). These selectivity patterns are likely too narrow to be real, although dogfish at times do segregate by age which is a possible explanation for the pattern. Fits to the survey data (Model 5 example in Figure A1.16) do vary

among models, but the jump in catchability in the summer survey associated with the gear change, as well as the lack of fit to the sharp declines in the cod4vsw and Georges RV surveys, are characteristic of all model fits. This sharp decline is more likely representative of a change in distribution rather than a change in overall abundance.

The spawner-recruit relationship for Model 5 (Figure A1.17), indicative of little to no density dependence in the processes determining abundance, was similar in all 6 models. If this pattern holds true in subsequent analyses, the implication for fisheries management is that the MSY reference points, which are based on the concept of a compensatory density dependent response to decreased abundance, would not have meaning for this population, at least over the range of abundances observed here.

Numbers-at-age (Model 5 example in Figure A1.18) indicate an issue with the fit for some models: the estimated abundance in the starting year is unrealistically low and influences abundance during those first years. Residual plots for the proportions-at-length (Figures A1.19) show some issues with model fit. Particularly with the summer RV data, the residual pattern is skewed with respect to age, and also shows a pattern through time, with larger residuals in the earlier and later years.

While the output from this model must be treated with caution, the 6 scenarios presented here all place spawner abundance in 2006 in the range of 5 to 35 million. If the models with α =4 are not included (say if the productivity was deemed unreasonably high), then the higher estimates are about 20 million. The commercial length frequency data suggests that the mode of the selectivity curves for the fisheries are typically near or above the age of 50% maturity. If true, dogfish are afforded the opportunity to reproduce prior to being removed by the fishery.

The following modifications to the model in its next iteration are suggested as ways to improve the model:

1. Compile the commercial catch and RV data on the same spatial scale so that spatial structuring within the population and movement between areas can be examined more readily.

2. Although the model is a two sex model, some parameters are common between the two sexes. Modelling the two sexes completely separately may improve model performance particularly if the spatial distribution differs between sexes. Separate q's may improve the selectivity curves.

3. The variability in the proportions-at-length in some of the data series may be contributing to the unrealistic selectivity curves presented herein. In this version of the model, sample size is assumed constant. Using the actual sample sizes might improve the fits, particularly if the more extreme observations are the result of small samples.

4. The assumption in the present model that the standard deviation of length-at-age is constant is likely unrealistic and a topic for further research.

Population Modelling:References

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Table A1.1. Constants used in the assessment model.

Component	Parameter	Females	Males
Growth	L_∞	105.74	82.42
(Von Bertalanffy)	t_0	0.0647	0.1365
	k	-5.678	-2.633
Growth variability	b_0	5.1131	6.236
(linear)	b_1	0.0674	-0.1162
(constant)		5.827	4.4323
Length to weight	b_i	1.3e-6	8.5e-6
conversion	b_{ii}	3.2695	2.81
Maturity	A_{50}	11	11
(logistic)	a	-9.0672	-9.0672
	b	0.57551	0.57551
Maximum age		31	31
α (SR slope at origin- age-1 recruits per spawner)	α	estimated or constant in the model range 2-15 pups every 2nd year, average 6, mortality to age-1 unknown, values of 1.25, 2 or 4 age-1 recruits/spawner used as constants	
Natural mortality		juveniles: 0.1, adults: 0.15	

Table A1.2. Parameter estimates and reference points obtained from three models fit to the summer survey data only. Numbers in brackets are standard errors. Values in bold were held constant.

		Model 1	Model 2	Model 3
Differing data		summer survey only	summer survey only	summer survey only
Differing assumptions:		σ =1.25, Mimm=0.1,Mmat=0.15	σ =2, Mimm=0.1,Mmat=0.15	σ =4.0, Mimm=0.1,Mmat=0.15,
OFV		-4028.65	-4051.88	-4061.73
Starting Pop. Size	N1	5.37e+007 (6.61e+006)	2.82e+007 (2.01e+006)	1.37e+007 (6.93e+005)
Spawner – Recruit	Rasym	**50,000,000,000**	**50,000,000,000**	**50,000,000,000**
	alpha	**1.25**	**2**	**4**
	SPRF0	8.35e-001	8.35e-001	8.35e-001
Survey Catchabilities	log.q.old	-6.13e-001 (2.28e-001)	-6.41e-00 (2 2.18e-001)	-4.21e-001 (1.70e-001)
	log.q.new	3.76e-001 (2.12e-001)	4.80e-001 (1.75e-001)	2.71e-001 (1.66e-001)
Reference Population Sizes	SSNeq	na	na	na
	20% SSNeq	na	na	na
	Req	na	na	na
	SSNmsy	na	na	na
Reference Fishing Mortality Rates	Fmsy	na	na	na
	Fcol	0.005	0.18	0.69
	F35%	0.46	0.52	0.54
	F45%	0.30	0.33	0.34

Table A1.2 (con't)

		Model 1	Model 2	Model 3
Differing data		summer survey only	summer survey only	summer survey only
Differing assumptions:		σ =1.25,	σ =2,	σ =4.0,
		Mimm=0.1,Mmat=0.15	Mimm=0.1,Mmat=0.15	Mimm=0.1,Mmat=0.15
Survey Sel. (old)	SfullF	1.00e+001 (9.16e-002)	1.24e+001 (2.37e-001)	8.24e+000 (5.97e-002)
	SfullM	1.15e+001 (7.80e-002)	1.17e+001 (2.79e-001)	1.19e+001 (4.55e-001)
	varLestF	1.00e+000 (1.28e-004)	1.56e+000 (7.66e-001)	1.00e+000 (1.13e-004)
	varLestM	1.00e+000 (4.47e-004)	1.42e+000 (8.65e-001)	1.70e+000 (1.55e+000)
	varRestF	1.00e+000 (1.63e-004)	1.00e+000 (3.85e-004)	1.00e+000 (2.79e-004)
	varRestM	1.00e+000 (2.52e-004)	1.00e+000 (2.89e-004)	1.00e+000 (1.30e-002)
Survey Sel. (new)	SfullF	8.60e+000 (3.03e-001)	8.83e+000 (2.81e-001)	9.02e+000 (2.55e-001)
	SfullM	1.44e+001 (3.28e-001)	1.45e+001 (3.39e-001)	1.45e+001 (4.35e-001)
	varLestF	3.63e+000 (9.13e-001)	4.13e+000 (8.69e-001)	4.38e+000 (8.09e-001)
	varLestM	2.44e+001 (1.67e+000)	2.31e+001 (1.59e+000)	2.16e+001 (1.74e+000)
	varRestF	2.67e+001 (3.19e+000)	2.64e+001 (3.17e+000)	2.73e+001 (3.17e+000)
	varRestM	4.75e+000 (2.31e+000)	4.61e+000 (2.38e+000)	3.94e+000 (2.93e+000)
Longline Selectivity	SfullF	1.68e+001 (6.94e-001)	1.76e+001 (8.67e-001)	1.76e+001 (6.10e-001)
	SfullM	1.39e+001 (1.51e+000)	1.39e+001 (1.50e+000)	1.39e+001 (1.40e+000)
	varLestF	6.46e+000 (2.30e+000)	8.45e+000 (2.73e+000)	7.88e+000 (1.90e+000)
	varLestM	1.00e-001 (1.32e-003)	1.00e-001 (1.31e-003)	1.04e-001 (5.90e-002)
	varRestF	9.71e+000 (6.05e+000)	5.07e+000 (6.29e+000)	5.10e+000 (4.48e+000)
	varRestM	1.00e-001 (1.24e-003)	1.00e-001 (1.24e-003)	1.01e-001 (1.90e-001)
Gillnet Selectivity	SfullF	1.60e+001 (1.44e+000)	1.65e+001 (2.76e+001)	1.54e+001 (7.12e-001)
	SfullM	1.50e+001 (1.33e+000)	1.50e+001 (1.32e+000)	1.50e+001 (1.25e+000)
	varLestF	1.00e-001 (1.18e-003)	1.02e-001 (1.44e+001)	1.44e-001 (2.87e-001)
	varLestM	1.00e-001 (1.11e-003)	1.00e-001 (1.10e-003)	1.00e-001 (2.39e-002)
	varRestF	1.00e-001 (1.27e-003)	1.02e-001 (1.60e+001)	1.83e-001 (1.41e+000)
	varRestM	1.00e-001 (1.14e-003)	1.00e-001 (1.14e-003)	1.01e-001 (2.26e-001)

Table A1.3. Parameter estimates and reference points obtained from three models fit to the six survey indices. Values in bold were held constant constants. Standard errors are not available for these fits.

		Model 4	Model 5	Model 6
Differing data		all data	all data	all data
Differing assumptions:		σ =2, higher start value Mimm=0.1,Mmat=0.15	σ =2, lower start value Mimm=0.1,Mmat=0.15	σ =4.0, Mimm=0.1,Mmat=0.15,
OFV		-5036.1	-5132.7	-5170.25
Starting Pop. Size	N1	2.7624e+007	1.87275e+007	1.39467e+007
Spawner – Recruit	Rasym	**50,000,000,000**	**50,000,000,000**	**50,000,000,000**
	alpha	**1.25**	**2**	**4**
	SPRF0	8.35e-001	8.35e-001	8.35e-001
Survey Catchabilities	log.q.sum.old	-0.517291	0.30654	-0.43554
	log.q.sum.new	0.5279	1.53874	0.217287
	log.q.spring	0.440966	1.42587	0.59711
	log.q.fall	-0.455722	0.605823	-0.342385
	log.q.cod4vsw	-0.919652	0.11707	-0.784505
	log.q.georgea	0.248816	0.949543	-0.477234
	log.q.sentinel	-15.9508	-14.3377	-16.7042
Reference Population Sizes	SSNeq	na	na	na
	20% SSNeq	na	na	na
	Req	na	na	na
	SSNmsy	na	na	na
Reference Fishing Mortality Rates	Fmsy	na	na	na
	Fcol	0.18	0.29	0.69
	F35%	0.51	0.69	0.52
	F45%	0.32	0.57	0.33

Table A1.3 (con't).

		Model 4	Model 5	Model 6
Differing data Differing assumptions:		all data σ =2, higher start value Mimm=0.1,Mmat=0.15 female, male	all data σ =2, lower start value Mimm=0.1,Mmat=0.15 female, male	all data σ =4.0, Mimm=0.1,Mmat=0.15, female, male
Survey Sel. (old)	Sfull	8.22382, 11.7182	8.35326, 11.8004	8.24266, 11.8738
	varLest	1.01299, 1.30333	1.00009, 1.79935	1, 1.47236
	varRest	1.00041, 1.00762	1.00287, 1.03143	1, 1.00001
Survey Sel. (new)	Sfull	8.76661, 14.4454	7.86545, 14.2832	9.02168, 14.4412
	varLest	3.98061, 22.8483	1.6279, 19.8312	4.41071, 21.2204
	varRest	27.3904, 4.91497	34.0004, 5.01073	27.4349, 5.11335
Longline Selectivity	Sfull	17.2696, 14.1072	19.374, 9.79057	17.5344, 13.9775
	varLest	7.04805, 0.10008	11.7988, 0.100311	7.63424, 0.100542
	varRest	7.21632, 0.124961	0.100034, 6.70764	5.79547, 0.100039
Gillnet Selectivity	Sfull	15.2887, 15.2963	15.1443, 15.0612	15.3945, 15.0194
	varLest	0.119596, 0.234336	0.154669, 0.122186	0.100018, 0.100063
	varRest	0.725911, 0.100915	5.43982, 0.111424	0.235538, 0.10006

Table A1.4. Estimates of population size obtained from three models fit to the summer survey data. See text for model descriptions.

Differing data Differing assumptions:		Model 1 summer survey only σ =1.25, Mimm=0.1,Mmat=0.15	Model 2 summer survey only σ =2, Mimm=0.1,Mmat=0.15	Model 3 summer survey only σ =4.0, Mimm=0.1,Mmat=0.15
SSN	1960	4.38e+007 (5.39e+006)	2.30e+007 (1.64e+006)	1.12e+007 (5.66e+005)
	1970	4.21e+007 (5.34e+006)	2.16e+007 (1.65e+006)	1.00e+007 (5.78e+005)
	1980	2.65e+007 (5.25e+006)	1.28e+007 (2.02e+006)	6.30e+006 (1.01e+006)
	1990	3.00e+007 (5.51e+006)	2.09e+007 (2.75e+006)	1.74e+007 (2.00e+006)
	2000	2.43e+007 (5.42e+006)	1.92e+007 (3.37e+006)	2.20e+007 (3.56e+006)
	2006	2.24e+007 (5.48e+006)	2.15e+007 (3.91e+006)	3.41e+007 (5.18e+006)
N	1960	5.04e+008 (6.20e+007)	2.65e+008 (1.88e+007)	1.29e+008 (6.51e+006)
	1970	4.92e+008 (6.28e+007)	3.63e+008 (2.73e+007)	3.11e+008 (1.70e+007)
	1980	3.74e+008 (6.28e+007)	2.76e+008 (3.25e+007)	2.41e+008 (2.53e+007)
	1990	3.28e+008 (6.33e+007)	2.93e+008 (4.24e+007)	3.80e+008 (4.96e+007)
	2000	3.10e+008 (6.37e+007)	3.39e+008 (5.29e+007)	5.99e+008 (8.64e+007)
	2006	2.81e+008 (6.38e+007)	3.49e+008 (6.08e+007)	8.09e+008 (1.25e+008)
N	2006/1960	5.57e-001 (5.80e-002)	1.31e+000 (1.36e-001)	6.27e+000 (6.63e-001)
	2006/2000	9.05e-001 (1.97e-002)	1.03e+000 (1.86e-002)	1.34e+000 (1.45e-002)
SSN	2006/1960	5.10e-001 (6.22e-002)	9.32e-001 (1.03e-001)	3.03e+000 (3.13e-001)
	2006/2000	9.22e-001 (1.95e-002)	1.11e+000 (8.21e-003)	1.54+000 (1.50e-002)

Table A1.5. Estimates of population size obtained from three models fit to the 6 survey data series. See text for model descriptions.

		Model 4	Model 5	Model 6
Differing data		all data	all data	all data
Differing assumptions:		σ =2, higher start value Mimm=0.1,Mmat=0.15	σ =2, lower start value Mimm=0.1,Mmat=0.15	σ =4.0, Mimm=0.1,Mmat=0.15
SSN	1960	2.25401e+007	1.52809e+007	1.138e+007
	1970	2.10882e+007	1.37833e+007	1.02485e+007
	1980	1.22055e+007	4.7073e+006	6.67832e+006
	1990	1.99716e+007	8.30922e+006	1.81693e+007
	2000	1.79763e+007	5.15528e+006	2.33383e+007
	2006	1.9996e+007	5.42373e+006	3.59004e+007
N	1960	1.9996e+007	1.75748e+008	1.30883e+008
	1970	3.54399e+008	2.33383e+008	3.16284e+008
	1980	2.65724e+008	1.28991e+008	2.5014e+008
	1990	2.7904e+008	1.07266e+008	3.97299e+008
	2000	3.21313e+008	1.0717e+008	6.30414e+008
	2006	3.27606e+008	9.19957e+007	8.53597e+008
N	2006/1960	1.26373	0.523452	6.52181
	2006/2000	1.01959	0.858405	1.35402
SSN	2006/1960	0.88713	0.354935	3.15468
	2006/2000	1.11235	1.05207	1.53826

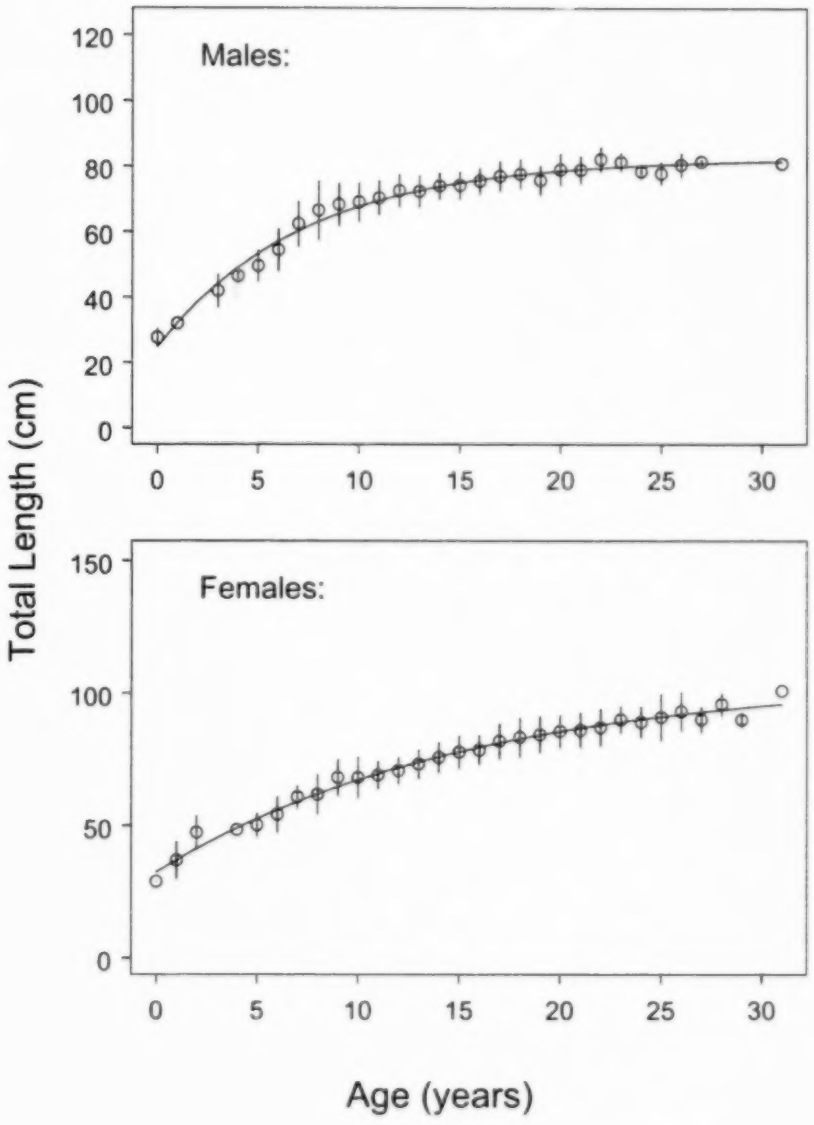


Figure A1.1. Observed (points) and predicted (lines) total length-at-age for male and female dogfish. Error bars are one standard deviation of the observed length-at-age.

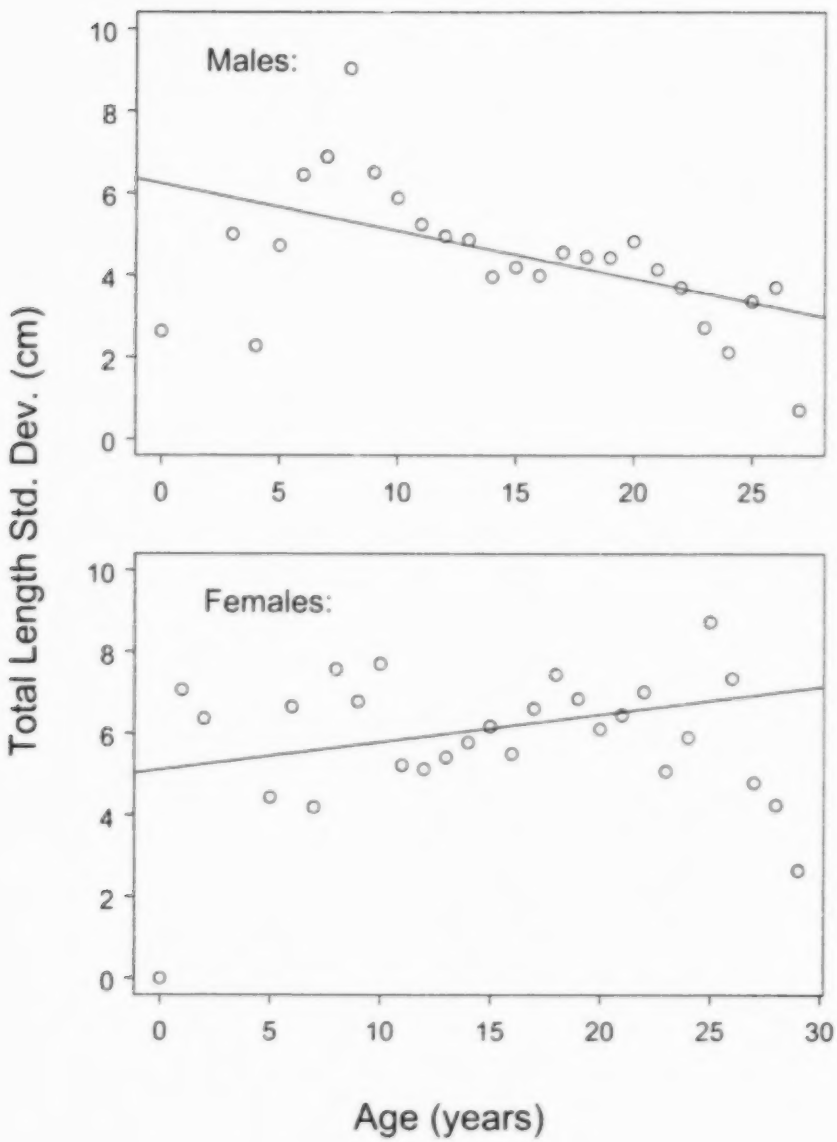
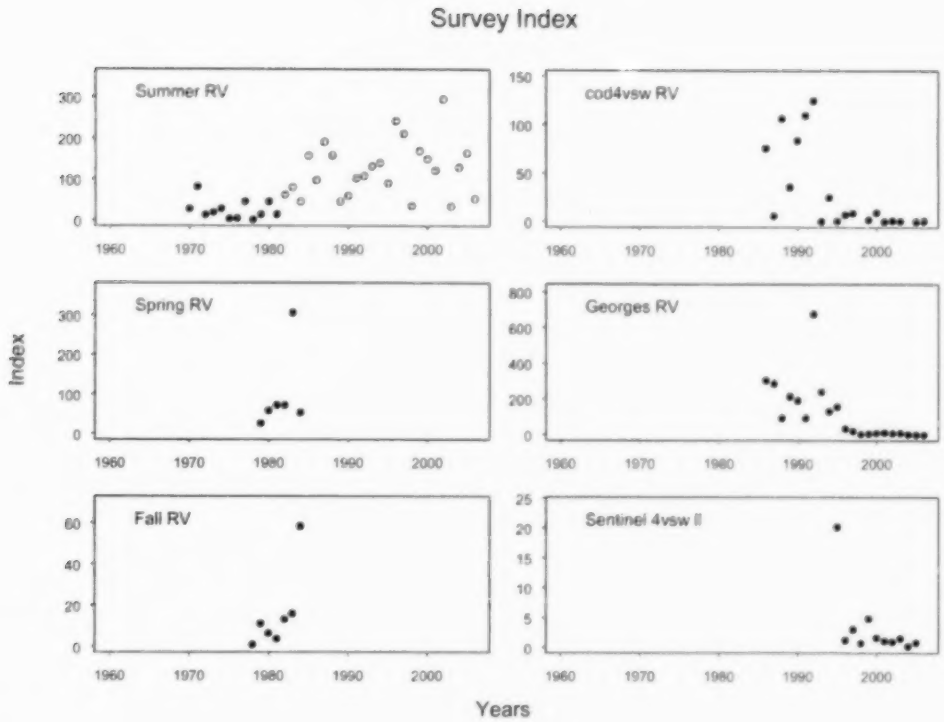


Figure A1.2. Relationship between the observed standard deviation of total length-at-age and age for male and female dogfish. The line is the least squares linear regression fit. A constant standard deviation was used in the model.



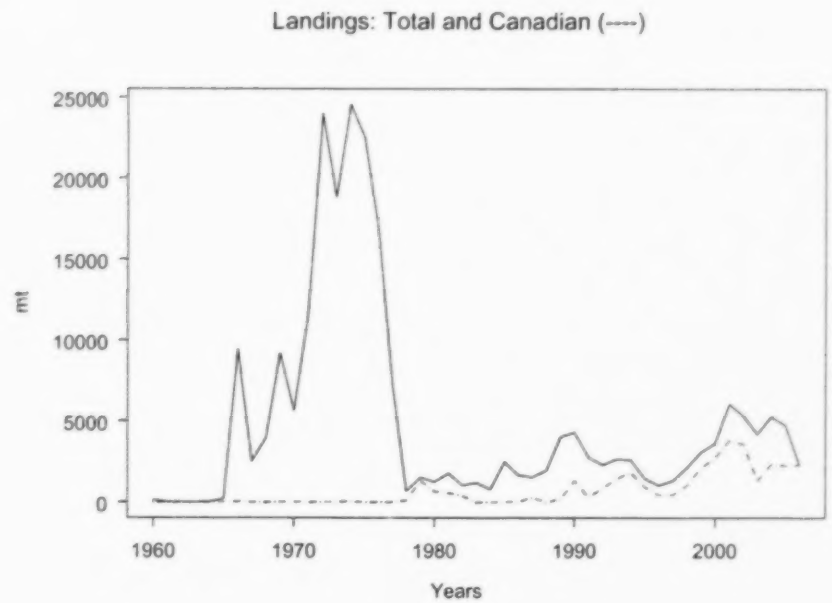


Figure A1.3. Survey index time series (top) and total and Canadian landings, excluding discards (bottom).

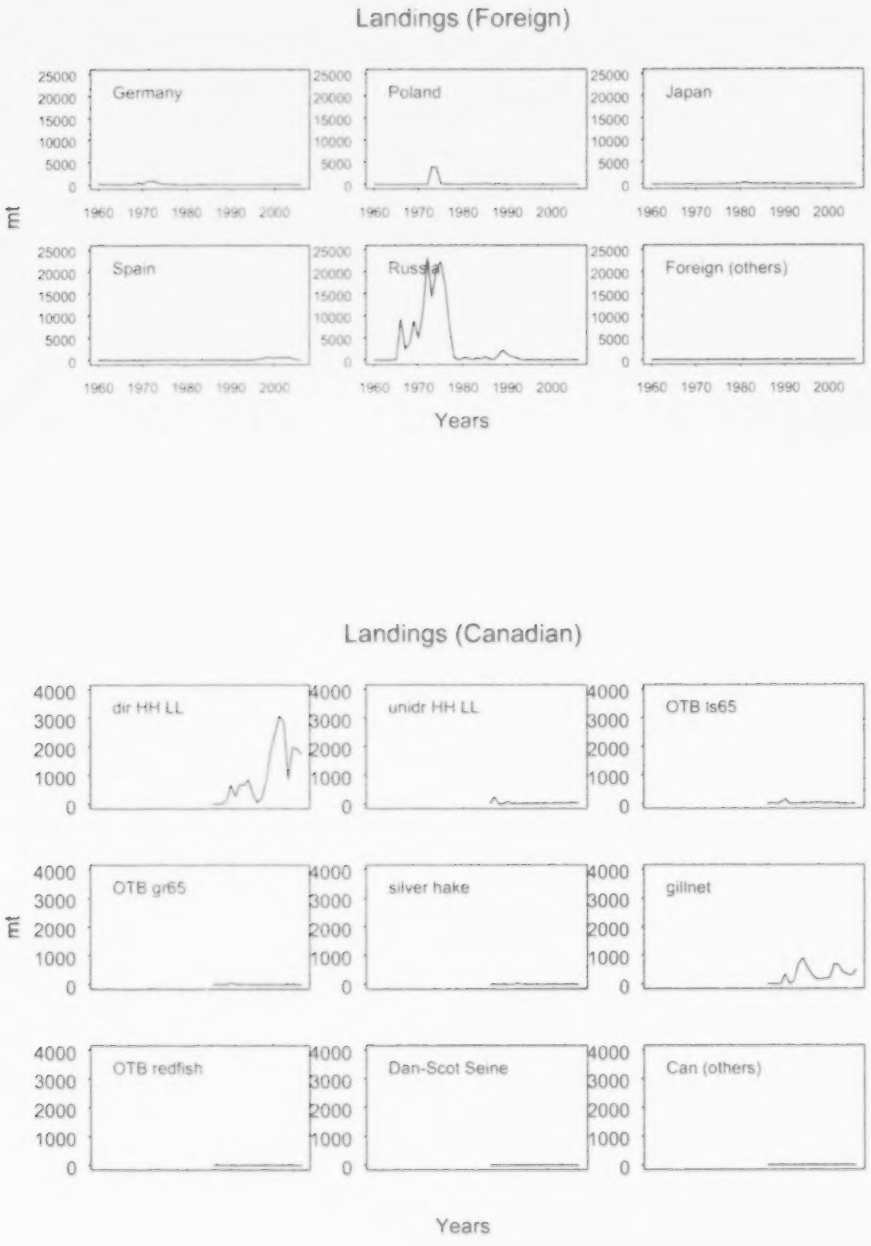


Figure A1.4. Landings by foreign (top) and Canadian fisheries (bottom).

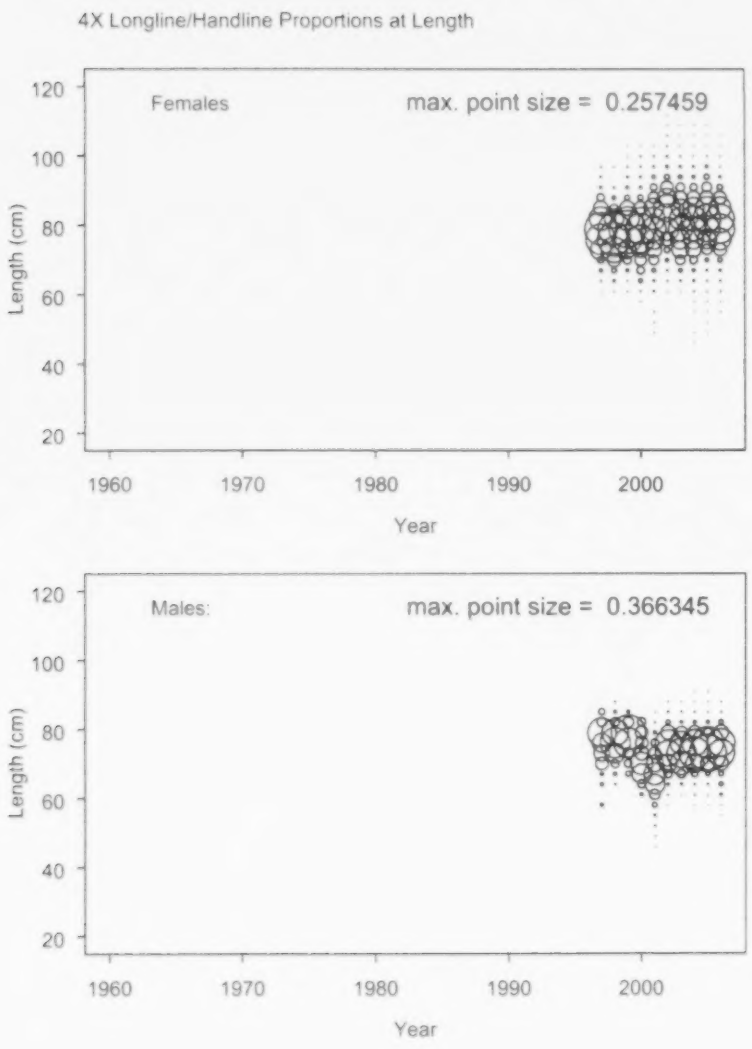


Figure A1.5. Proportions at length in the 4X handline/longline fishery.

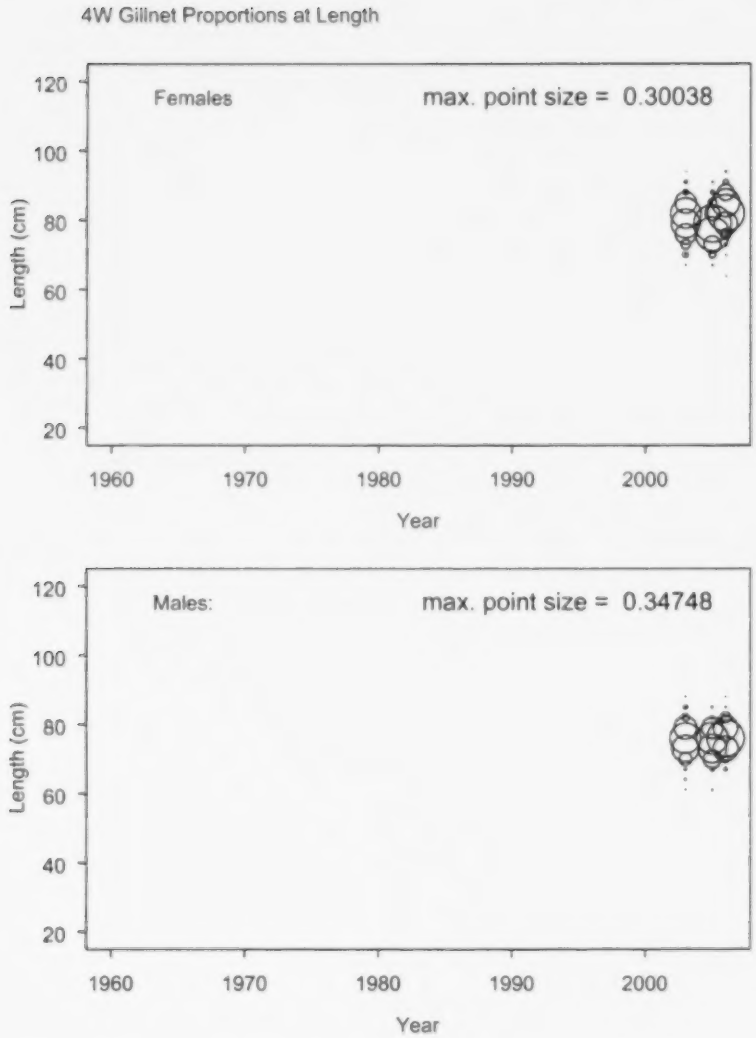


Figure A16. Proportions at length in the 4W gillnet fishery.

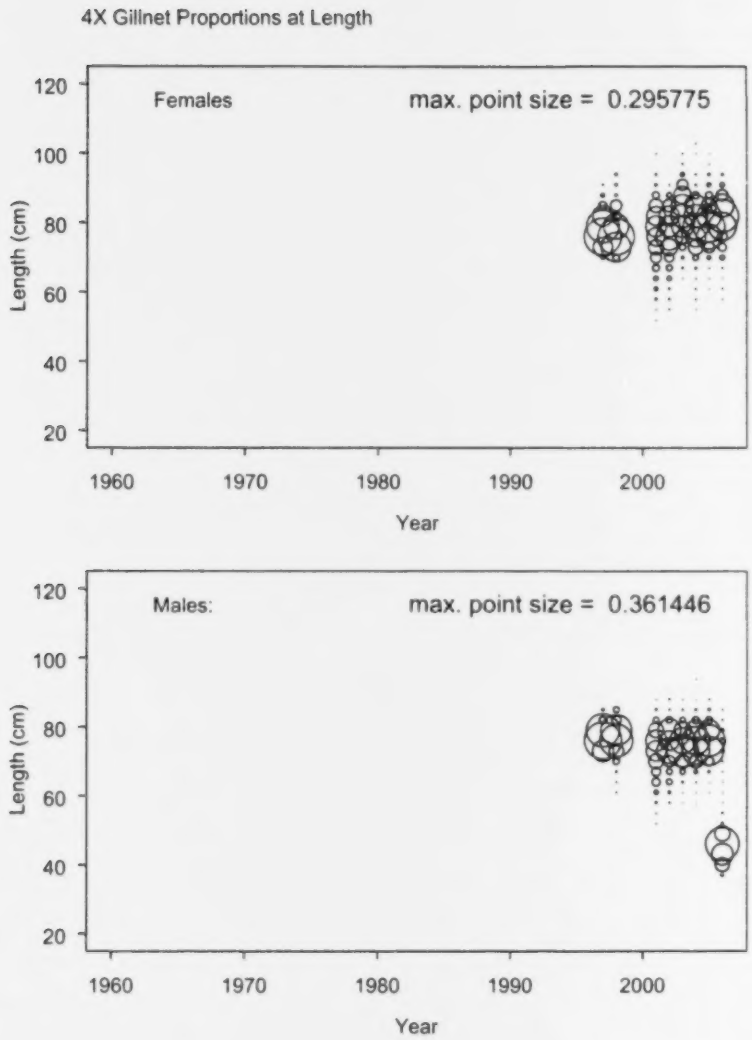


Figure A1.7. Proportions at length in the 4X gillnet fishery.

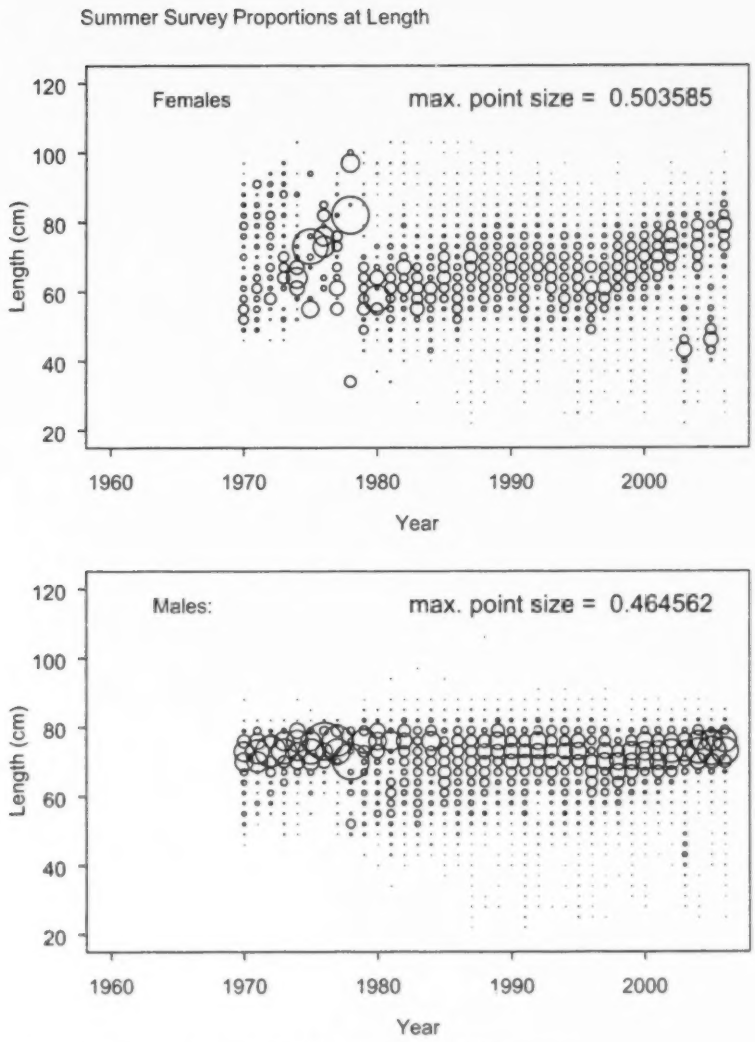


Figure A1.8. Proportions at length for the summer RV survey..

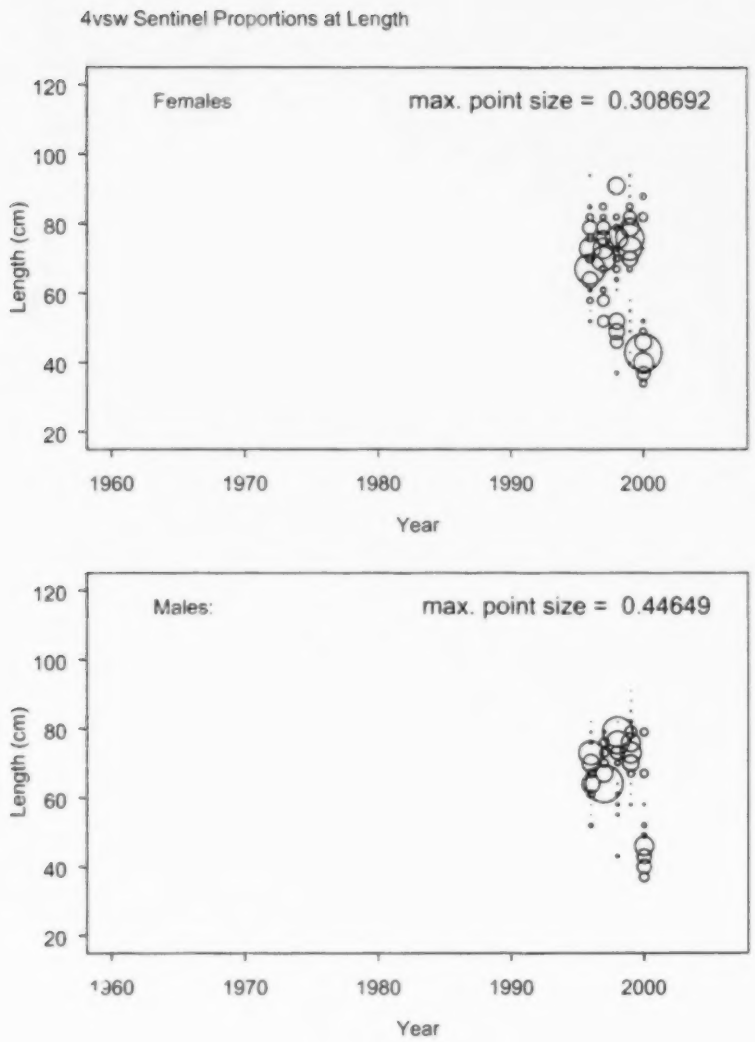


Figure A1.9. Proportions at length for the 4vsw sentinel survey.

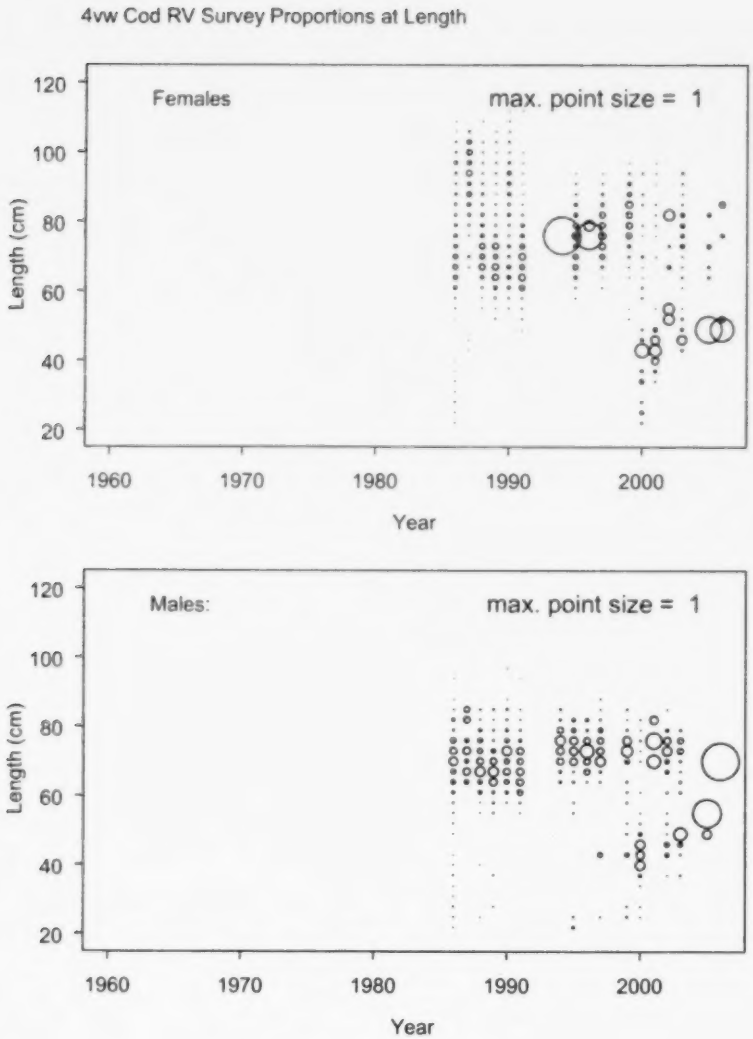


Figure A1.10. Proportions at length for the 4VsW cod RV survey.

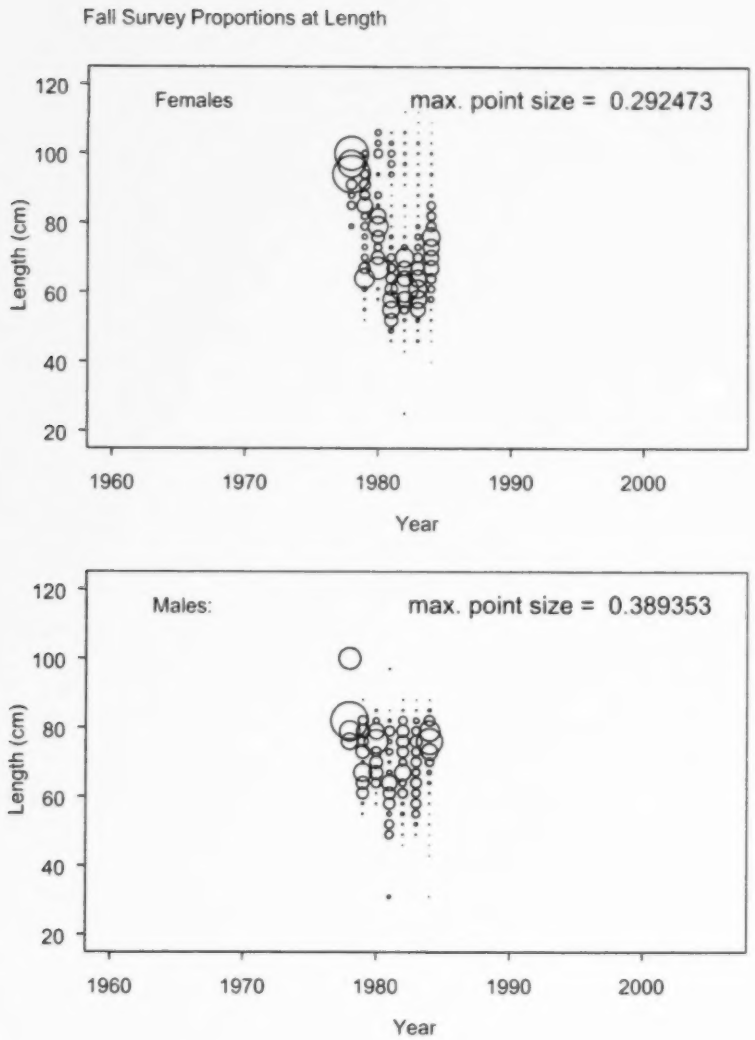


Figure A1.11. Proportions at length for the Fall RV survey.

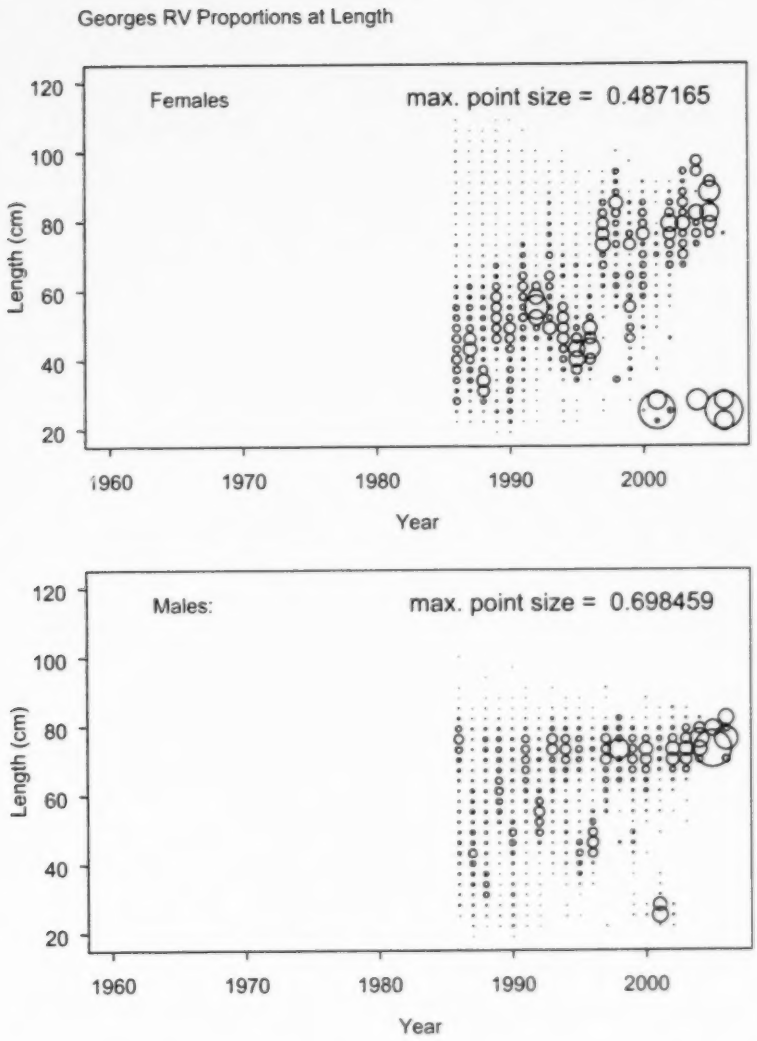


Figure A1.12. Proportions at length for the Georges RV survey.

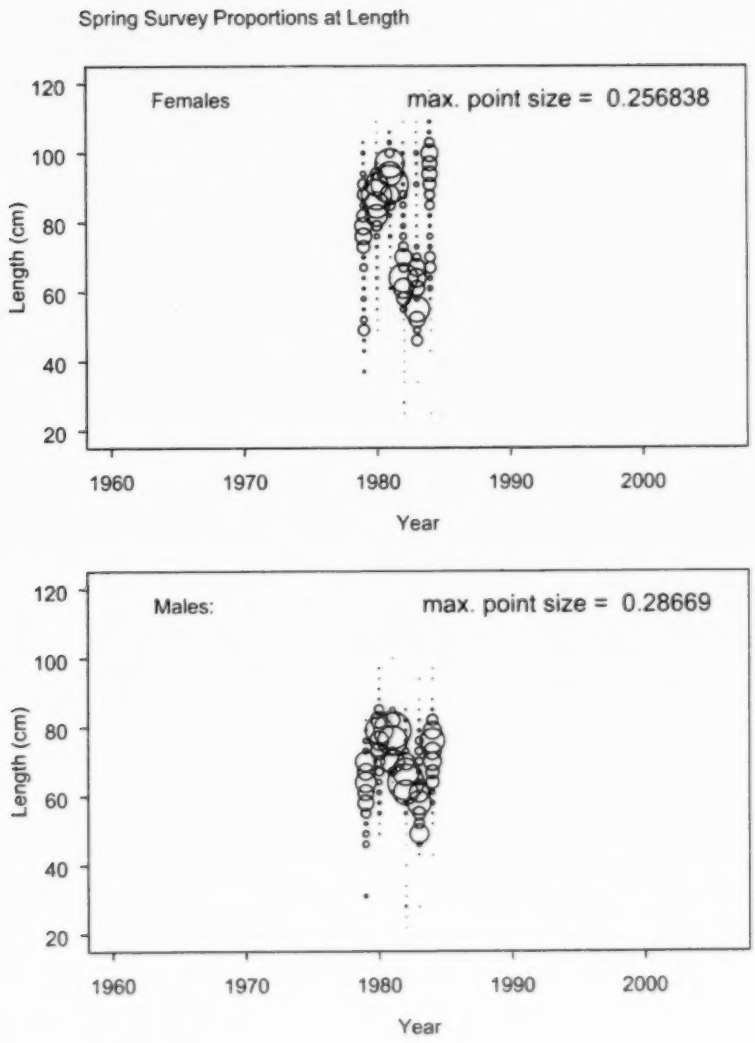


Figure A1.13. Proportions at length for the Spring RV survey.

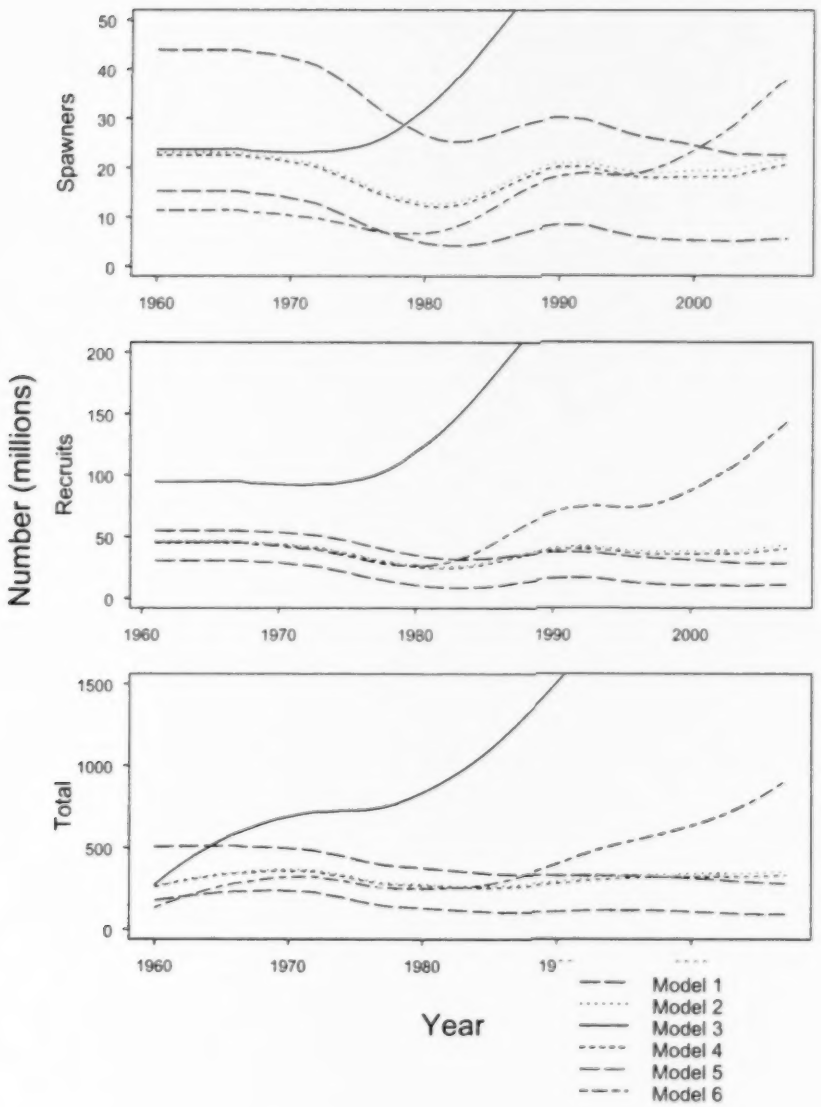


Figure A1.14. Comparison of the predicted time series for female spawner abundance, recruitment at age-1 and total number from each of the six models.

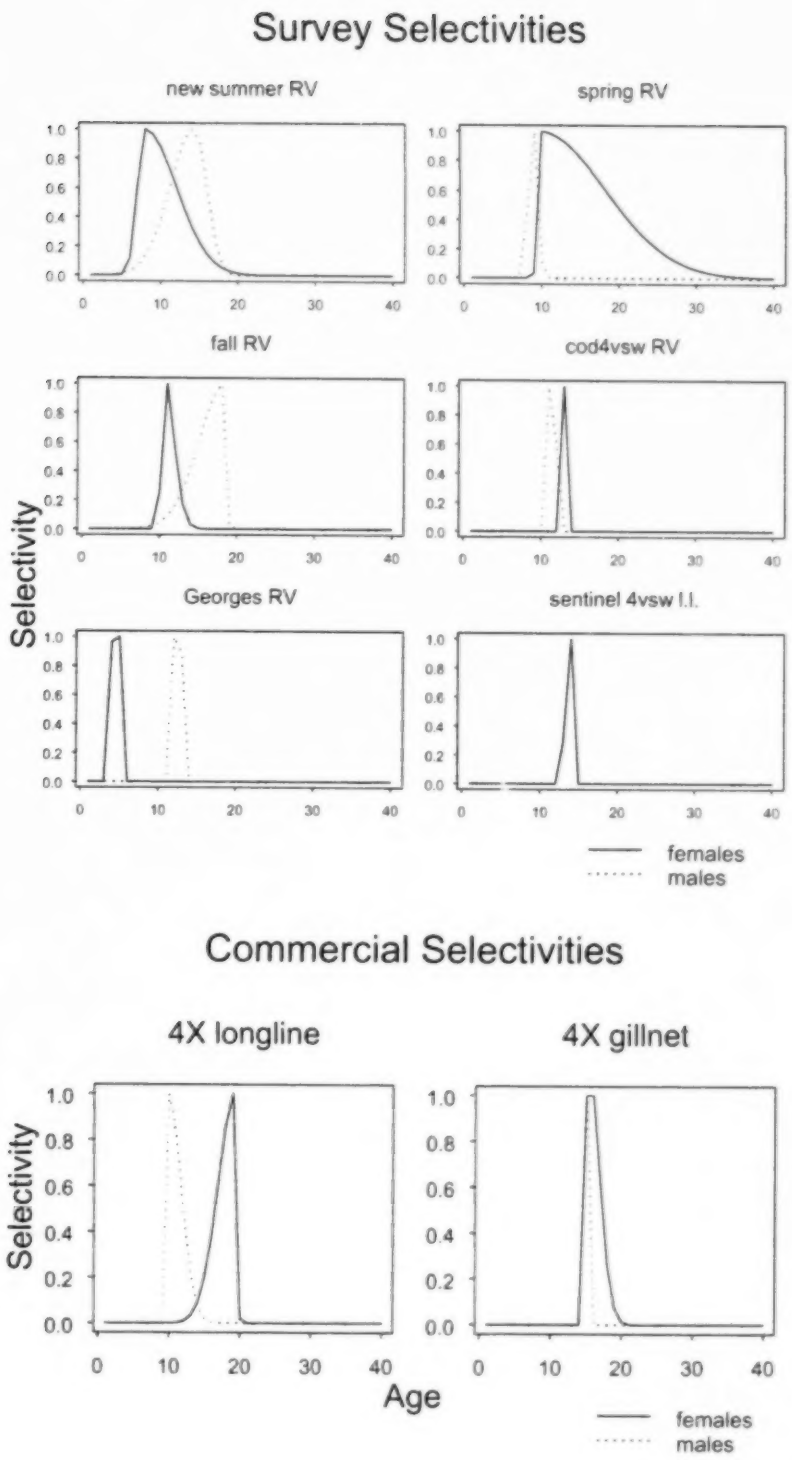


Figure A1.15. Model 5 (alpha=2; all data) estimated selectivities.

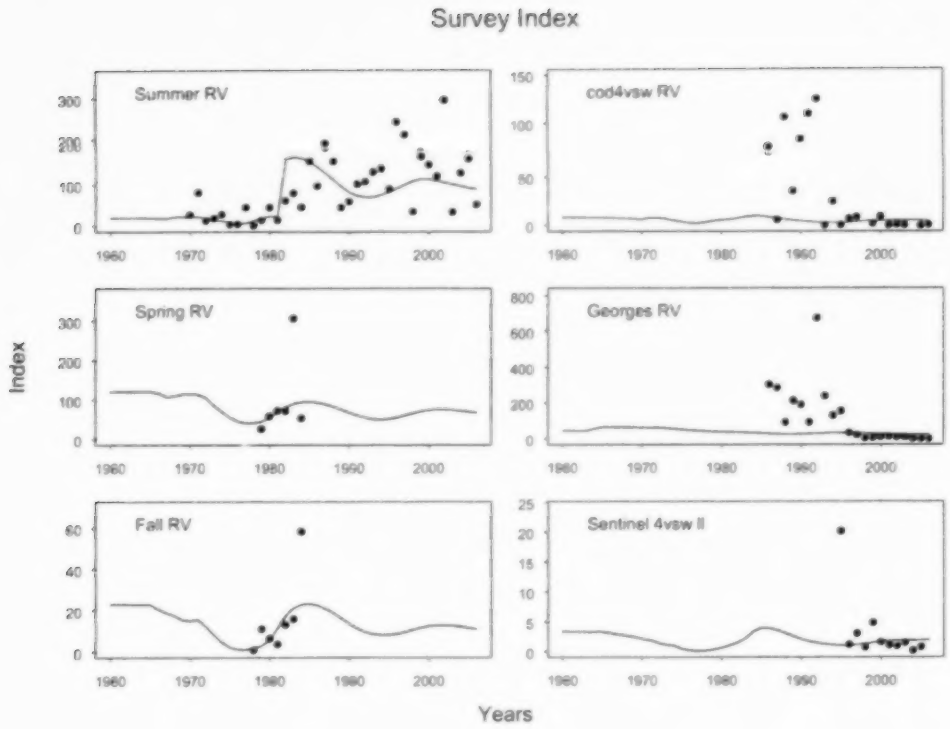


Figure A1.16. Model 5 (alpha=2; all data) observed and predicted summer RV index.

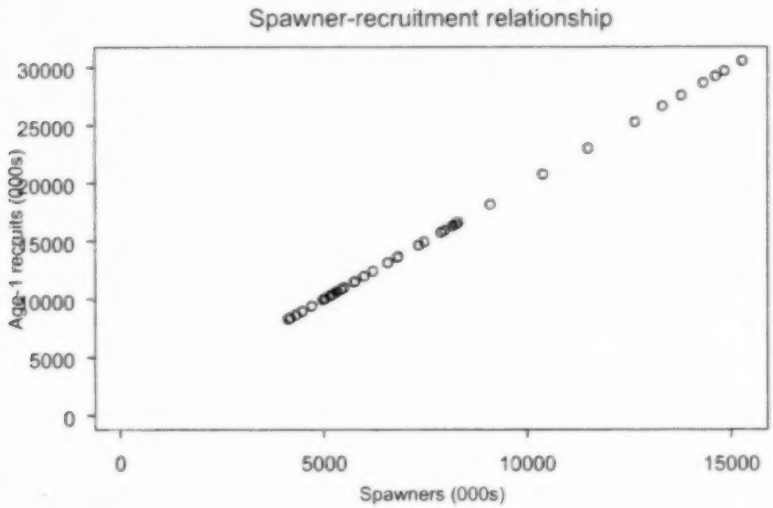


Figure A1.17. Model 5 (alpha=2; all data) spawner-recruit relationship.

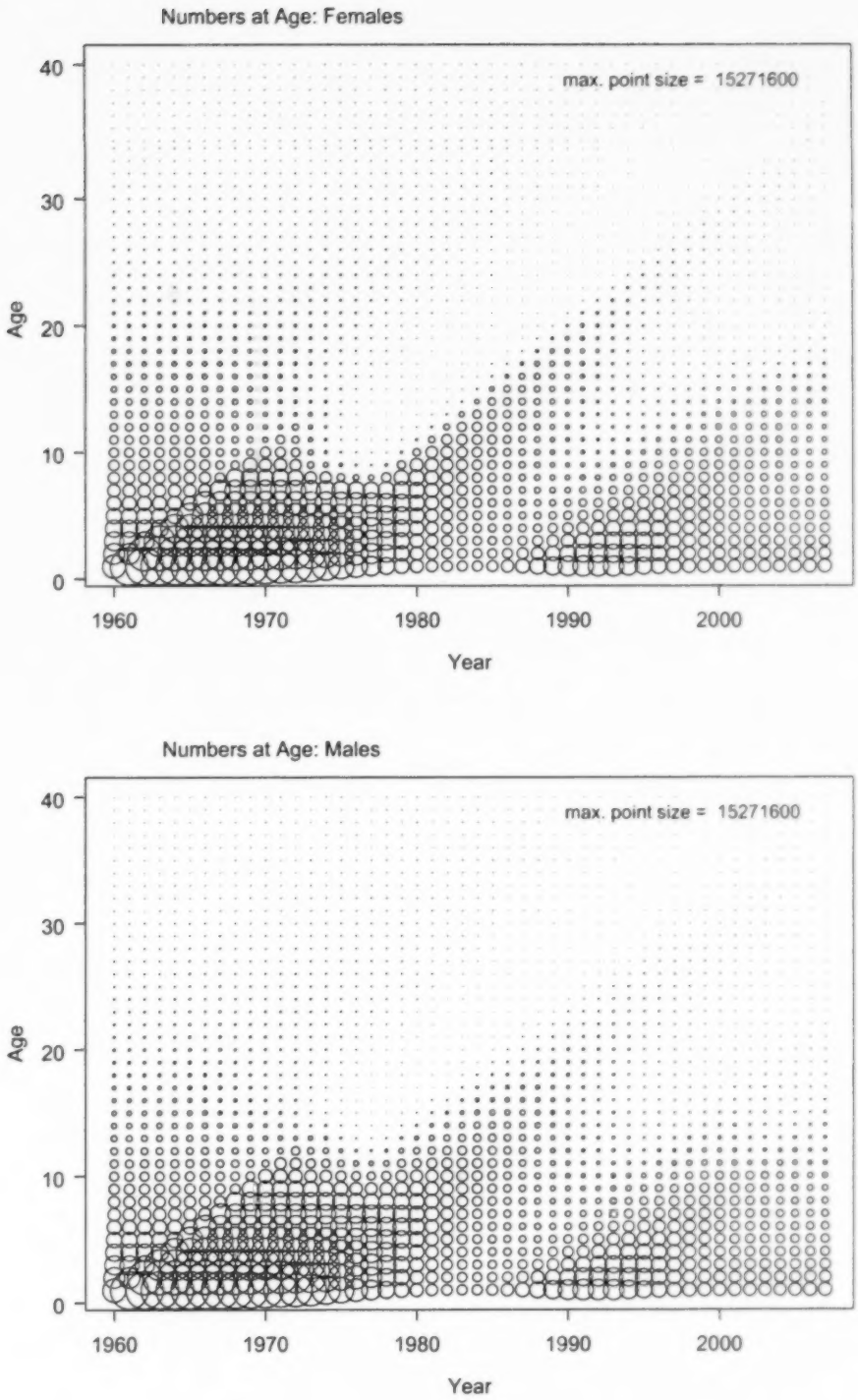


Figure A1.18. Model 5 (alpha=2; all data) predicted numbers at age.

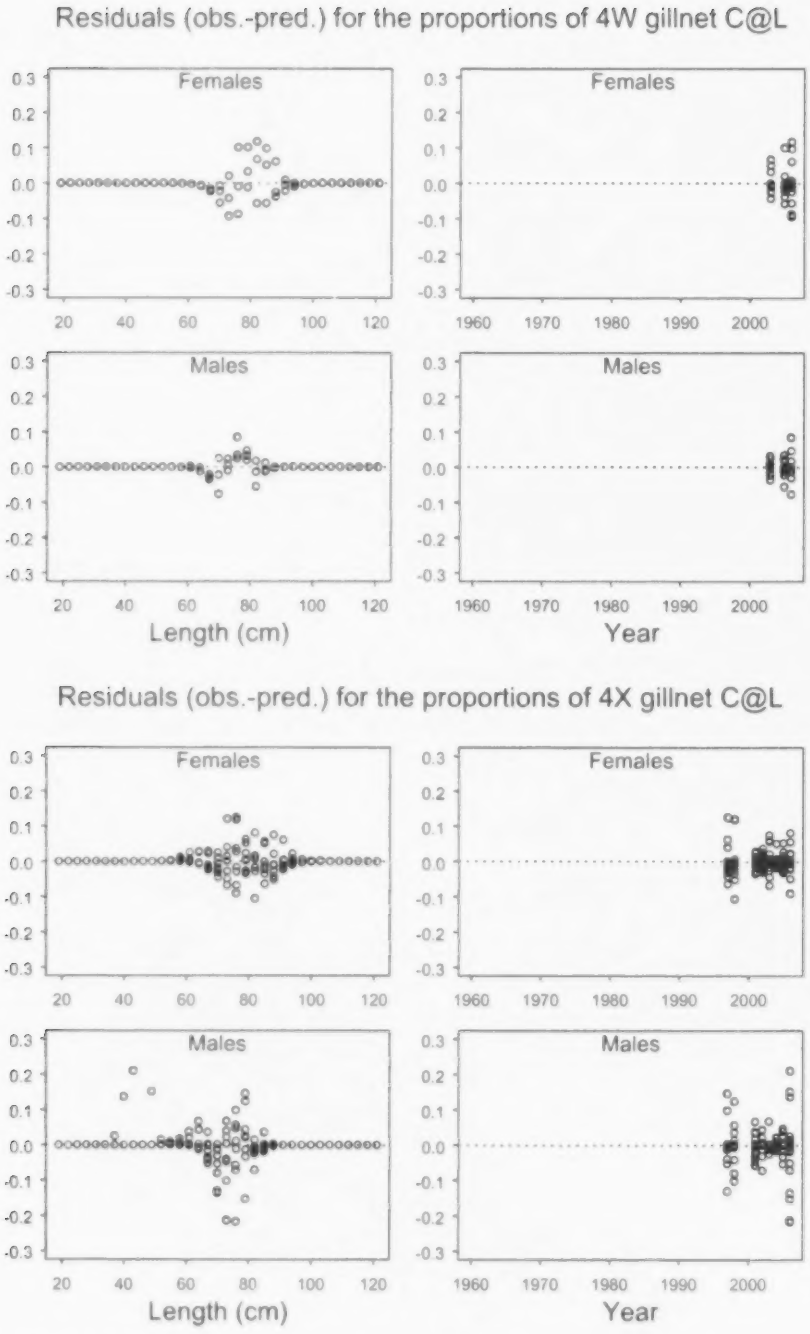


Figure A1.19. Model 5 (alpha=2; all data) raw residuals for proportions-at-age.

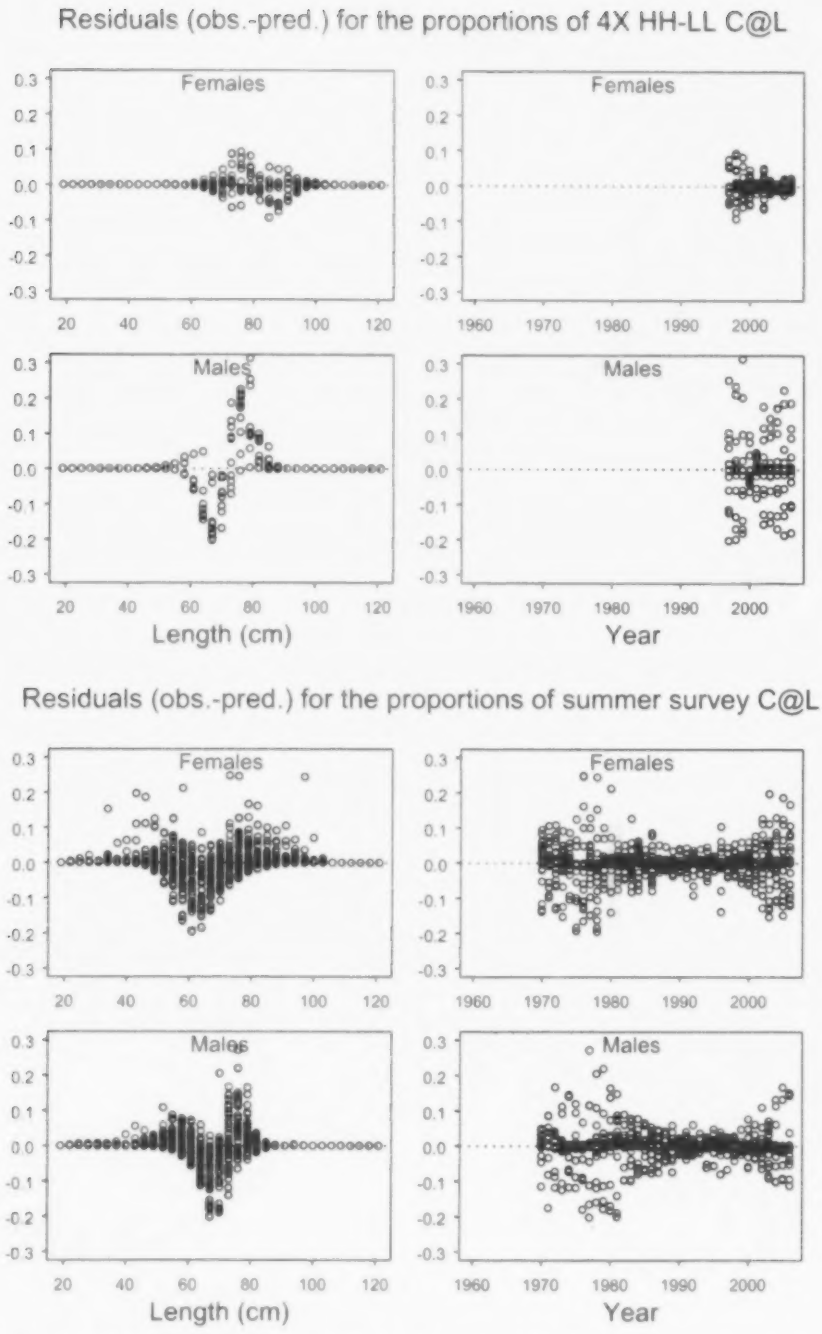


Figure A1.19 (con't). Model 5 (alpha=2; all data) raw residuals for proportions-at-age.

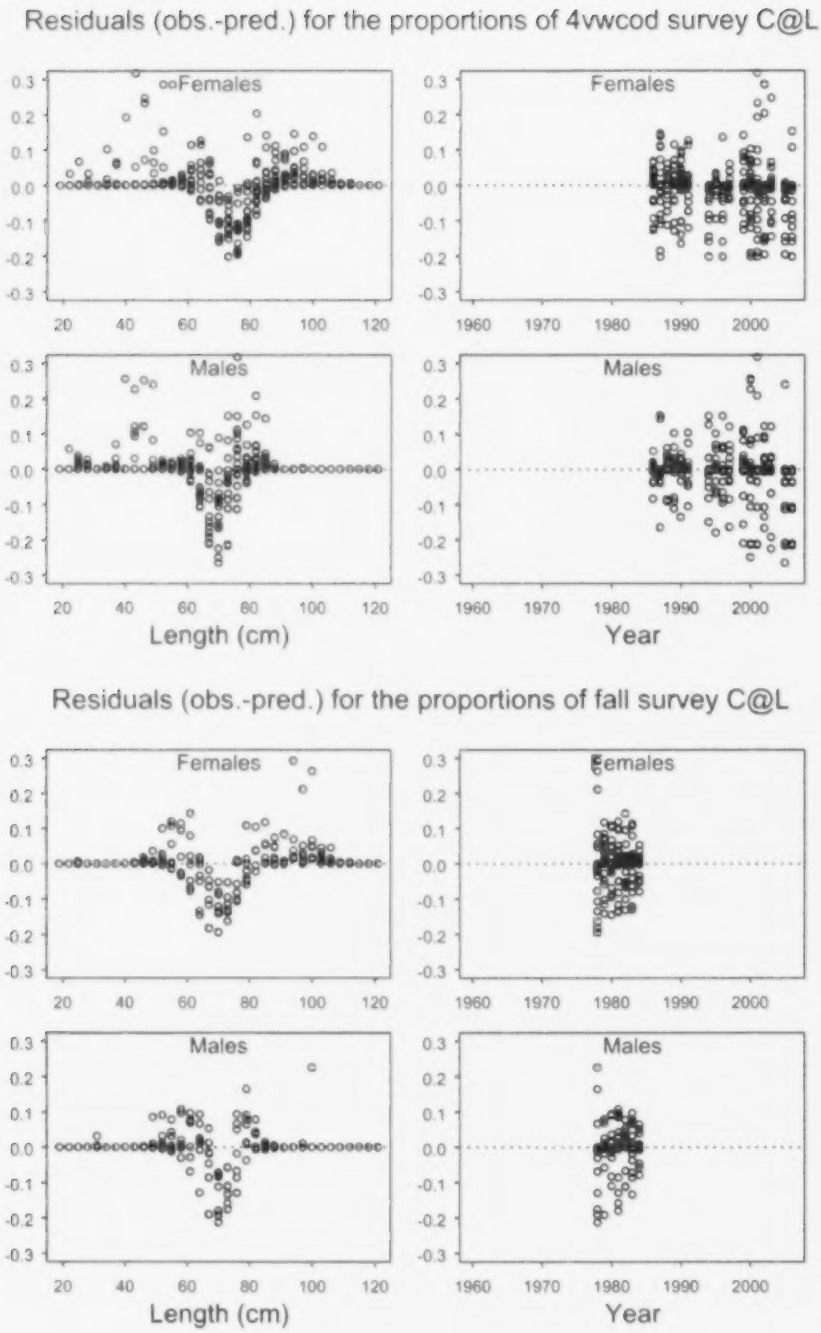


Figure A1.19 (con't). Model 5 (alpha=2; all data) raw residuals for proportions-at-age.

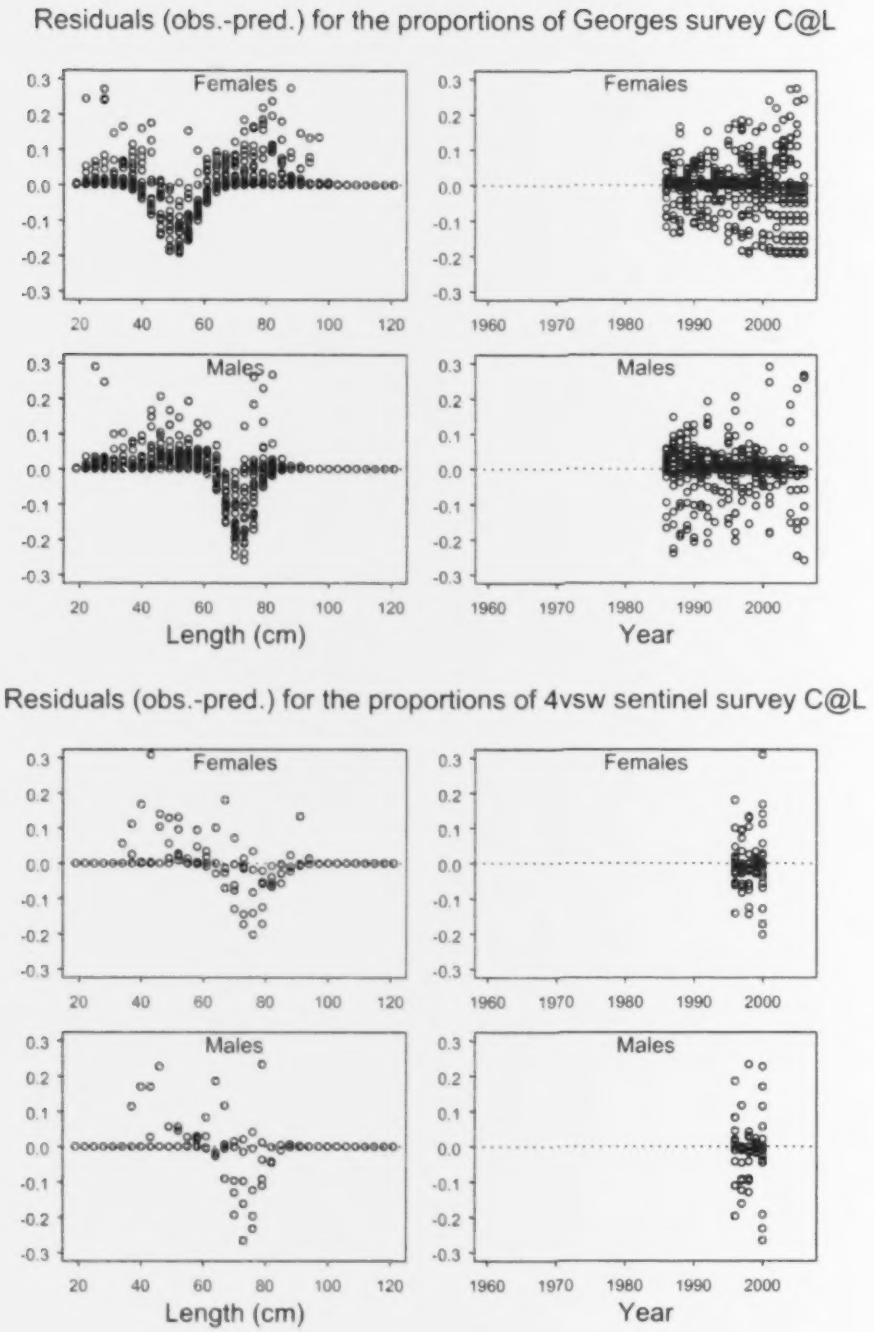


Figure A1.19 (con't). Model 5 (alpha=2; all data) raw residuals for proportions-at-age.

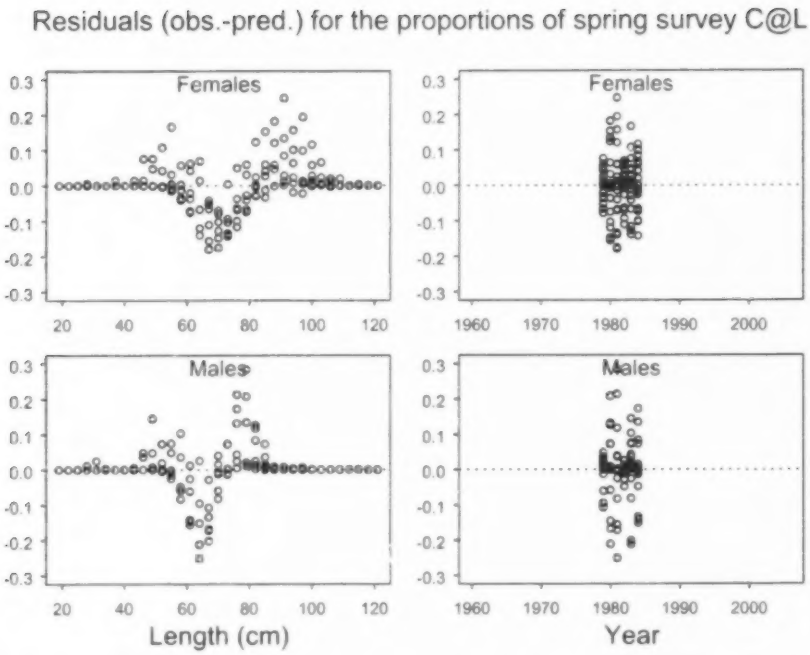


Figure A1.19 (con't). Model 5 (alpha=2; all data) raw residuals for proportions-at-age.